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PRESSURE VESSEL TESTING USING STRAIN MEASURING TECHNIQUES

by

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SYNOPSIS

The paper outlines the pressure vessel test procedures, instrumentation and practical experience gained from the tests carried out by Technical Investigations Department since early 1950. The purpose of the tests varied, some were carried out to satisfy the requirements of a particular specification, some to establish an allowable working pressure by means of a proof test and some to allow a vessel to enter into service when a dimensional tolerance was outside specification. The paper discusses the results obtained from the various tests and compares the test results with design calculations. The application of shakedown procedures and the results obtained are shown and the metallurgical aspects of the shakedown are discussed.

The pressure tests called for measuring techniques and methods which ranged from simple strain measurements in a few nominated positions using a manual strain meter to a complex multi-channel installation of over one and a half thousand strain gauges monitored by a mini-computer based data logger. The part of the paper devoted to instrumentation and measurements outlines, by example, the selection of strain gauge locations and the type of the gauges used in relation to anticipated stress fields and environment. The installation techniques of strain gauges for both normal and abnormal test conditions and the factors governing the choice of manual or computer based instrumentation are described. The paper illustrates the development of measuring and gauge installation practice and points out the advantages of the new techniques including the characteristics of two computer controlled data loggers in current use.

Finally, the requirements of various national standards with respect to experimental pressure vessel testing are discussed and illustrated using examples from recent past.

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1. INTRODUCTION

Technical Investigation Department (TID) has been working in the field of pressure vessel testing since the beginning of 1950 when the prototype United Kingdom nuclear reactor containment vessels of Calder Hall and Chapel Cross were fabricated. At the same time measurements on a wind tunnel and petrochemical vessels were undertaken and the foundations for large scale strain measurements were laid.

The early tests were carried out to requirements and specifications which were formulated on the basis of each particular investigation. Gradually the work was influenced by the development of national standards and in particular, by the sections directly related to experimental stress analysis.

The present TID investigations are mainly carried out in accordance with applicable standards and recognised test procedures.

Measurement techniques have undergone substantial changes from manual data acquisition using strain meters and switch boxes to mini-computer controlled, multichannel data loggers. For stress monitoring more than 95% of the TID pressure vessel work employs electrical resistance strain gauges. Additional techniques include measurements of deflection, temperature and pressure and, where control over environmental conditions can be exercised, qualitative and quantitative measurements of strain using brittle lacquer techniques can be employed.

Most of the early vessels tested by TID were pneumatically pressurised and in order to obtain a detailed local stress analysis strain gauges were fitted to both internal and external surfaces of the shell. Hydraulically pressurised vessels posed problems at first because techniques for waterproofing strain gauges were not perfected. By about 1960 better techniques had been established and a near 100% success rate can now be achieved.

The majority of the work presently being carried out by the department is related to three fields of interest. Firstly, it carries out measurements to satisfy the requirements of various standards or specifications applicable to a particular vessel. Secondly, it investigates the suitability of pressure vessels for an intended service when a doubt exists as to the vessel's compliance with a particular specification, or when the submitted calculations do not give an adequate degree of reliability. And thirdly, it assists with new designs by carrying out theoretical calculations and practical stress analysis of prototypes and models.

2. PLANNING AN INVESTIGATION

Each investigation can be divided into three parts. Planning and preparation; installation, measurement and analysis; and, not discussed in this paper, the issue of a report.

2.1 Strain Gauge Locations

Prior to measurements, the drawings of the pressure vessel are received and studied to establish suitable locations for the strain gauges, their total number and type. The strain gauges are positioned in such a way as to fully utilise the symmetry of the vessel and simultaneously provide sufficient coverage to obtain data from all critical areas.

The selection of the locations may be based on experience only or guided by calculations based on classical or finite element methods. It is particularly important to determine and include the most critically stressed part of the vessel in the list of areas to be strain gauged. It will be seen later in this paper that the number of pressure cycles to which the vessel must be subjected will be controlled entirely by the plotted results from this critical area.

The gauges are located as close to the stress concentration areas as physically possible. All the rosettes are orientated such as to have one limb in the direction of the principal axis of symmetry of the vessel. The internal gauges are aligned with the opposite external gauges in such a way as to achieve coincidence of the major axis of both rosettes.

In order to record the general membrane stress of the shell some gauges are fitted to the plain sections of the vessel away from the stress concentrations and structural discontinuities.

The gauges selected for use are invariably three element strain gauge rosettes or two element T-gauges. The strains in the plane section of the vessel can be measured using a three element rosette but in a number of cases where the directions of the principal planes are known, T-gauges positioned in the principal directions are used.

An advance visit to site is sometimes necessary to acquaint the contractors with the requirements of a strain gauge installation and its protection before a pressure test. At the same time the chosen gauge locations can be checked for feasibility. Other factors which must be allowed for at the planning stage are time and budget constraints, the type of test medium and additional strain gauge locations which may be requested by the client.

2.2 Preparation for Strain Gauge Installation

It is necessary to install strain gauge rosettes on each side of the vessel shell plate with reasonable accuracy. Location marking should be done carefully and indelibly so that when the metal surface is ground for gauging, the marking can be projected back to give the location and orientation of the gauge. It will be necessary to look at a detailed drawing of any adjacent weld preparation and mark the weld limits inside and outside the vessel so as to be able to locate the gauge centre line. It is easy to make large errors when siting gauges opposite one another, particularly when the branch or pad under consideration passes through a thick shell at an angle. Figure 1 shows a typical problem which is difficult to solve with accuracy by measurement but which is made very easy using ultrasonics. The method requires two transducers, one on an extended lead. It is essential to develop a technique using a sample plate of similar thickness but once established the method is fast and reliable. Good communication between the inside and outside locations is also essential. Other aids to location include centre lines or marks which are sometimes put on components at the time of manufacture and the use of squares and flexible straight edges to transfer a point round a machined flange.

Experience has shown that a vessel contractor cannot provide suitable labour and tools to prepare areas of the vessel to the standard required for strain gauging. The Department now has, therefore, a comprehensive set of pneumatic tools with flexible backing plates and rapidly interchangeable abrasive discs of grades from 50 grit to 180 grit and from $\frac{3}{4}$ inch to 3 inch

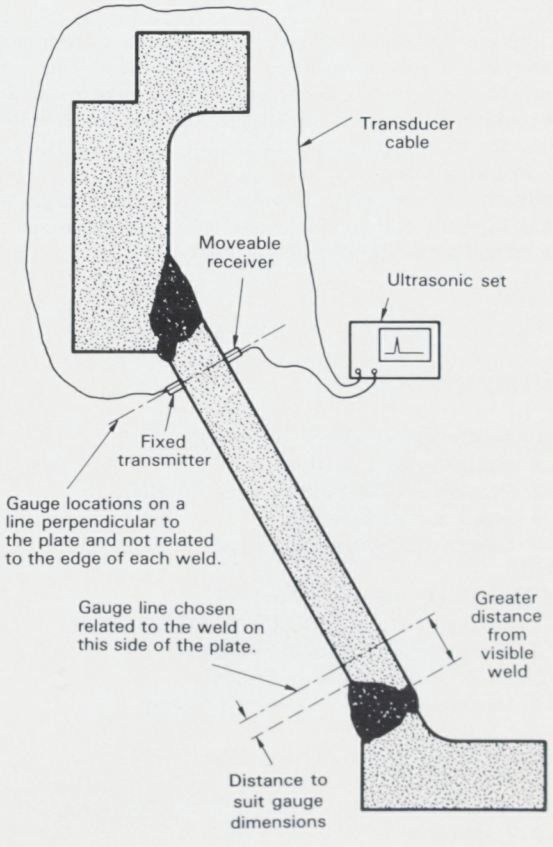


Fig. 1 Strain gauge location

diameter. In this way even boiler plate can be quickly reduced to a fine finish, needing only handwork with 220 and 400 grit paper.

The recommended techniques for preparing a ready ground area to which a strain gauge is to be bonded vary from one gauge manufacturer to another. The authors follow the technique described in Appendix A which requires wet lapping with metal conditioner followed by a water based neutralizer. The method is put forward as good practice and the following comments are offered in support:

(1) Properly carried out and with some practice it does not add significantly to the preparation time.

(2) The conditioner and neutralizer are water based and give no problem with toxic fumes and leave no deposits on the prepared surface.

(3) The standard of bond required of a gauge installation is high if the gauge has to measure static strains with good repeatability over a long time of high elongations.

It is recognized that in hot and humid conditions it can be difficult to use this technique due to rapid surface corrosion and under such conditions efforts must be made to reduce condensation on the surfaces intended for strain gauging.

A problem recently highlighted during a shakedown test in Northern Europe in winter was a gauge bond failure after the first strain cycle. The location was inside the vessel at a point of high strain and was attributed to condensation of water from human breath. In cold conditions it is almost impossible to avoid and it is strongly recommended that temporary local heat is applied in these conditions. The problem is aggravated at overhead and vertical surfaces on cold plate and poor lighting usually means vapour is invisible and the body is closer to the cold surface.

2.3 Strain Gauge Bonding

The choice of adhesive will depend on the conditions under which the bond will be made, the test environment, the accuracy expected and the type of gauge to be used. Three types of adhesive currently used for pressure vessel work are:

(1) A filled polyester cement Phillips type 9244/04. This is very widely used as it is rapid curing and not too sensitive to the curing environment. Static measurements may be taken after 15 minutes of curing at about 20°C.

(2) A very rapid 'super glue' or cyanoacrylate cement M-Bond type 200 which will allow measurements to be taken after 5 minutes at 22°C. This cement is only suitable for application in a warm environment and for measurements over a short term, say over weeks rather than months.

(3) A range of epoxy systems such as M-Bond AE-15 and M-Bond 600 which allow a thin glue line and give a long life, high stability and a high temperature capability. The cement requires a hot cure with a pressure clamp during the initial cure. These systems would be used for permanently installed gauges or for measurement at high temperatures.

Appendix B shows the basic characteristics of the above cements.

2.4 Choice of Strain Gauge Type

Appendix C shows the characteristics of commonly used strain gauges. Most pressure vessel work involves hazards for the strain gauge installation. These include physical damage as a result of the other concurrent work, damage due to weather conditions and in the case of a hydraulic test, the system must be proofed against hydraulic pressure. Practically all these hazards are mitigated by the use of the pre-wired and encapsulated gauge, a system which was pioneered by the Society. It is not unusual now to get all strain gauge limbs functioning in large vessel work and it would be unacceptable to test a vessel with more than 1 or 2% of the total number of gauges out of action. The technique can be applied to any type of gauge and transfers much of the more difficult side of gauge handling to the laboratory. Plate 1 shows an encapsulated rosette gauge and its compensator gauge ready for additional waterproofing and Plate 2 after its application to a test piece. Briefly the technique is to keep the wires off the vessel surface with bonded stand-off insulators so that the wire can be surrounded by the additional waterproofing compound. The wire which is usually PVC insulated has to be primed with a nitrile rubber solution to aid adhesion to the additional waterproofing compound which is a cold cured thiokol rubber. Plate 2 also shows two other waterproofing compounds in use on the test piece.

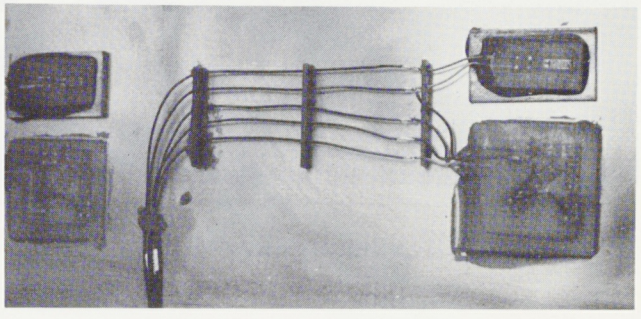


Plate 1 Triple strain gauge rosette and compensating gauge ready for waterproofing



Plate 2 Various waterproofing compounds applied to the strain gauges and ready for test

In recent years a series of pre-encapsulated gauges has been available from Japan. These need no additional waterproofing and are suitable for use up to a pressure of 100 kgf/cm^2 (*see* Note 1 below). Plate 3 shows an enlarged photograph of one of these Japanese stacked rosette gauges when installed. The active length of each of the three gauge grids is 5 mm. It can be seen that a smaller area of vessel surface is used resulting in a reduction of installation time.

The following factors must be considered when choosing a strain gauge for pressure vessel work:

(a) The size of the area to be gauged and the gradient of the strain. Obviously it must be possible to fit the gauge, its

(Note 1) The authors have endeavoured to use SI units where possible but data quoted from various specifications may not comply.



Plate 3 Japanese stacked rosette guage

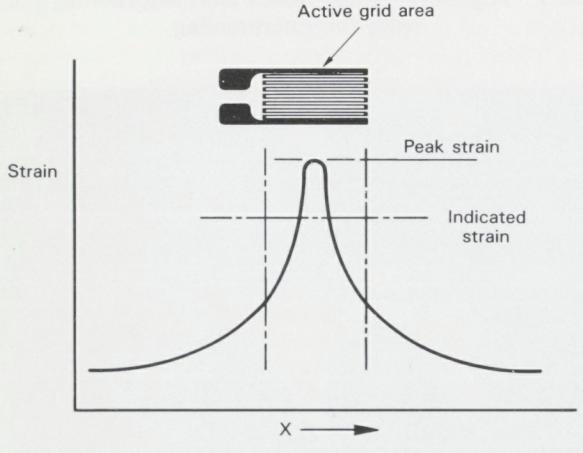


Fig. 2 Error in indicated strain due to gauge length

connections and substrata into the area in question. A gauge reads the average strain over the length of the active grid. Fig. 2 shows the error due to using a gauge which is too long for an area of high strain gradient. Examples of Japanese and American gauge lengths in common use are 5 millimetres and 0.25 inches. In an extreme case of high gradient, gauges have been used in chains of 10, each with an active length of 0.020 inches and spaced 0.035 inches apart.

(b) A further point for consideration is the homogeneity of the pressure vessel shell material. As an example a series of glass reinforced plastic pressure vessels were to be tested. The glass reinforcement included woven glass rovings having a weave pitch of several millimetres. Test bars representing the vessel layed-up material were strained and a series of strain gauges having a gauge length from 2 mm to 25 mm used to measure the strain. It was found that accurate results were not obtained except with gauges of 25 mm active length.

(c) Modern strain gauges are manufactured from specially developed alloys. One of the main properties of the alloys is that they offer a degree of self-temperature compensation. Temperature has two main effects on an installed gauge, firstly there is a change of resistivity of the gauge grid material and secondly there will be a difference between the thermal expansion of the vessel material and the strain gauge grid material. The combined effect of these two errors is termed apparent strain. Fig. 3 shows the apparent strain curve for gauge series EA, when bonded to a material with a coefficient of linear thermal expansion of $23.4 \times 10^{-6}/°C$. It can be seen that if the temperature of the test environment could be controlled there would be no need for additional temperature compensation. This situation rarely occurs in the Department's work and an additional temperature compensating gauge has to be used. Plate 4 shows an encapsulated gauge bonded to a steel block which can be used to compensate for wider changes of temperature.

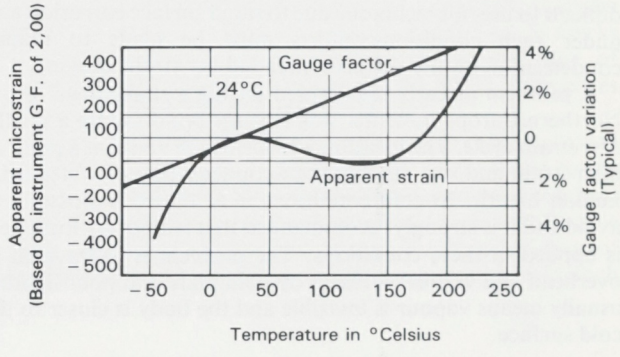


Fig. 3 Temperature induced apparent strain

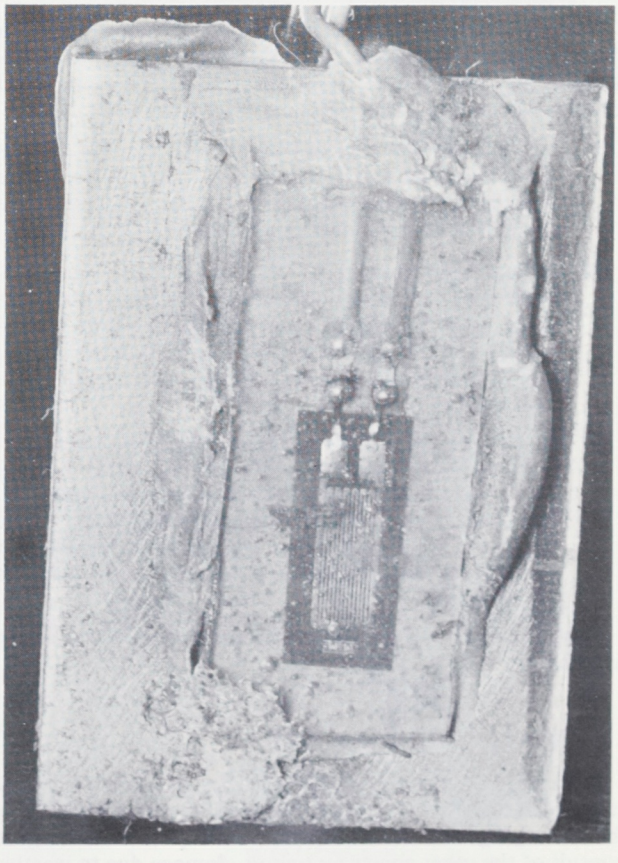


Plate 4 Encapsulated gauge fitted to a steel block used for temperature compensation

3. METHOD OF MEASUREMENT

3.1 Factors Governing the Choice of Equipment

With the recent addition of a Spectra data logger, the Department has a choice of three measuring systems, viz. a portable manually switched strain meter system; Spectra, a portable computer controlled data logger; and Compulog III, a larger transportable computer based system. The choice of the system depends on the number of points at which strain is to be monitored, the number of sets of readings to be taken, the location of the test and sometimes the test budget. The first two systems are easily transported by road or air as accompanied baggage and where necessary, customs clearance can be made on the spot. Compulog III has been transported many times in a medium sized van and ferries give access to Europe and Ireland. The use of this equipment further afield would, however, involve sea transportation and could only be justified on large scale investigations.

3.2 Description of Manual System

Plate 5 shows a modern portable strain indicator with a 24-way and a 48-way switch box. Manual systems have been in use since at least early 1950, the designs having changed from circuits using thermonic emission valves to the more compact tranisitorised versions.

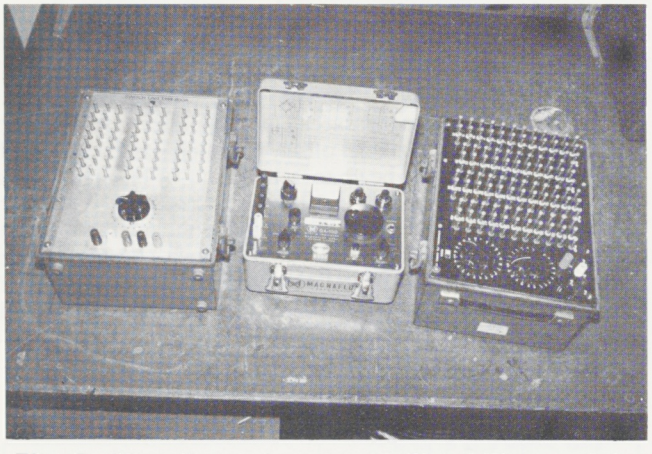


Plate 5 Magnaflux strain meter with 24 and 48 way switch boxes

The Department has a number of indicators and switch units available for small scale work and before the advent of data loggers there were enough switch boxes to cover the testing of large nuclear reactor containment vessels with up to 700 strain gauges. The gauges were usually grouped in triple rosette form and the readings from each rosette were used to calculate the principal stresses and angle of the principal plane using a special triple input slide rule.

The system is very portable and reliable and has an accuracy, stability and resolution equal to or better than some data logging equipment, particularly when the overall performance of each is considered. However, the manual system is labour and time consuming while the computer controlled systems can produce printed pages of results which can be reproduced directly in a report.

Fig. 4 shows a simplified circuit diagram of a portable strain meter. It is termed a reference bridge system. The measuring bridge contains a measuring gauge and a temperature compensating gauge attached to the vessel under test. These are connected by leads of suitable length to a pair of matching resistors in the instrument. The reference bridge consists of fixed and variable resistors in the instrument. The variable resistors consist of switched course balance resistors and an infinitely variable fine balance scaled resistor. Both bridges are energised by a common constant voltage AC supply with the addition of a sensitivity or gauge factor control in the supply to the reference bridge. An amplifier and null detector circuit detects the difference between the balance of the two bridges. The scaled variable resistor is adjusted until a null is reached and the scale reading is then read. The overall accuracy is about $\pm 0.1\%$ of the reading or 5 microstrain whichever is the greater. The scale can be read to 2 microstrain and the range of strains which can be accommodated is $\pm 50\,000$ microstrain.

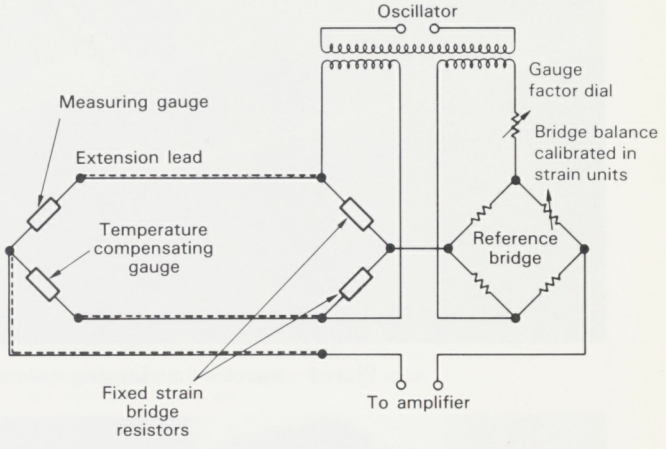


Fig. 4 Basic circuit diagram of a portable strain meter

3.3 Description of Spectra System

Plates 6 and 7 illustrate the complete Spectra Data Logging System as configured to handle up to 208 individual strain gauges. Plate 6 shows the mini-computer with keyboard, visual display and magnetic tape cartridge storage facility. Alongside is the dot matrix printer which can produce an A4 size page of results. The measurement system and scanner shown in Plate 7 can be sited up to 3 km from the host computer and communication is by a serial line cable link. The cable can be a simple screened twisted pair of wires. Connections for 208 strain gauges cannot be made directly onto the back of such a small unit and at present a crimped connection is made to stub leads permanently wired to the scanner trays.

The measurement system unit contains a microprocessor which performs the following functions: the scheduling of the system communication to and from the host computer or keyboard, diagnostic functions, serial-line interfacing, memory and controlling hardware for the interfacing and operation of the built-in firmware. The microprocessor's dynamic memory stores current scanning parameters and acts as a buffer store for results.

Tables 1, 2 and 3 show the basic logging options available with the system firmware and Table 4 relates the amplifier measurement ranges with the input resolution. Scale number 8 is usually used in pressure vessel work thus giving a resolution of 1.22 microvolts/bit, equivalent to strain resolution of 1.01667 microstrain at 2×5 mA bridge energisation and 120 ohm strain gauges.

The Spectra system of offsetting the initial balance condition of the strain gauge and its temperature compensator relies on a sequence of adjusting the two energising sources in a see-saw fashion until a balance condition is obtained. This condition is then automatically stored for each channel and re-applied as necessary for subsequent measurements. The current supplies,

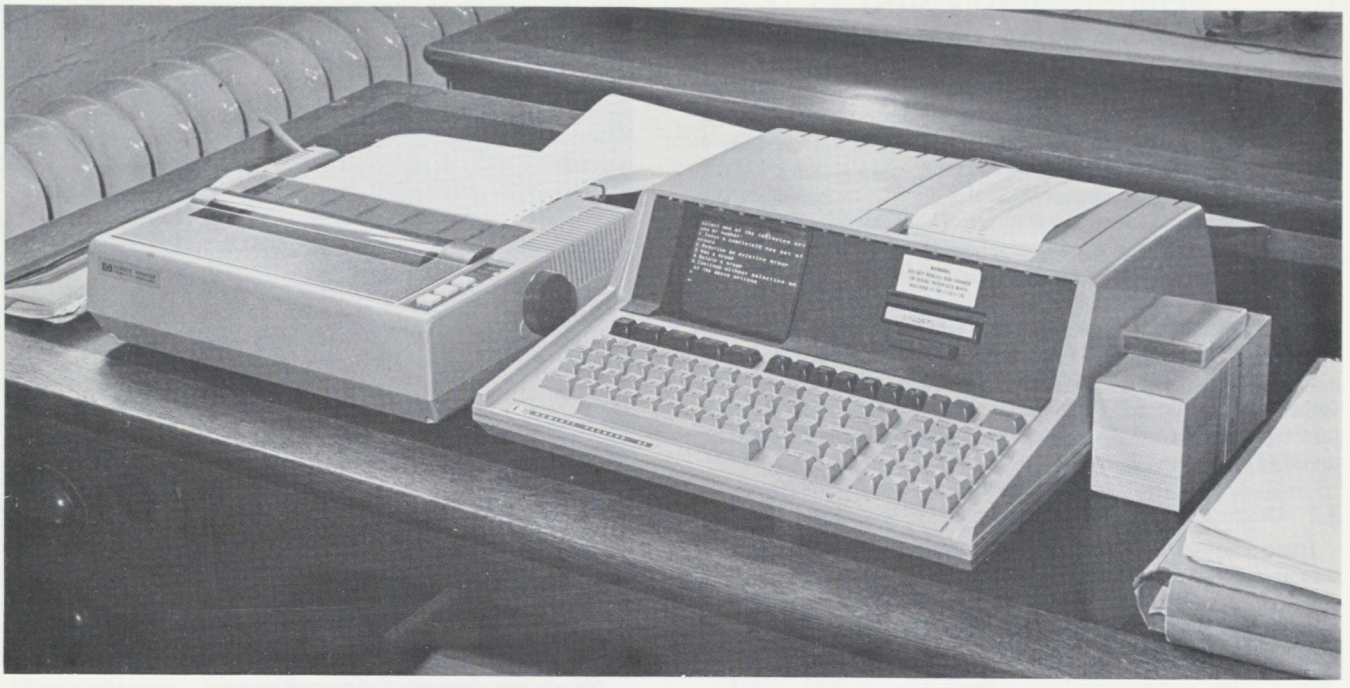


Plate 6 Spectra data logging system—HP.85 host computer and the dot matrix printer

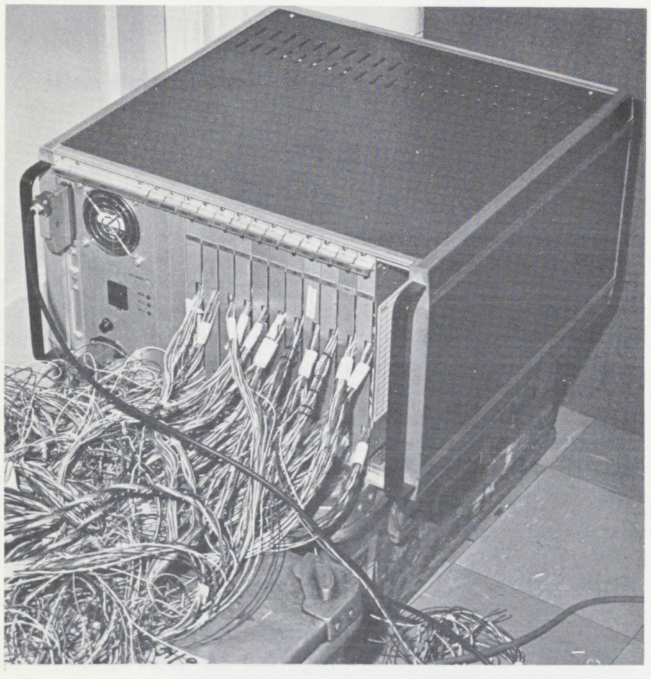


Plate 7 Spectra data logging system—208 channel scanner unit with built-in microprocessor

Table 1 Scale arguments

Argument Value	Scale FSD
0	10.24 V
1	5.12 V
2	2.56 V
3	1.28 V
4	640 mV
5	320 mV
6	160 mV
7	80 mV
8	40 mV
9	20 mV

therefore, change but are constant at a predetermined level at the time of measurement. Figure 5 illustrates the advantages of the balance system which is termed "Hardware Autobalance". It enables the full scale measurement range B to be retained or by programming an artificial offset, the range can be extended by a span P which may be up to $\pm 1.6\%$ out-of balance, this is equivalent to a strain offset of 32 000 microstrain. A further advantage of the system is the reduction in the number of reed relays necessary per channel in comparison with the Compulog system described later. Figure 6 shows a number of types of strain gauge connection of which the top example would normally be used.

Table 2 Energising arguments

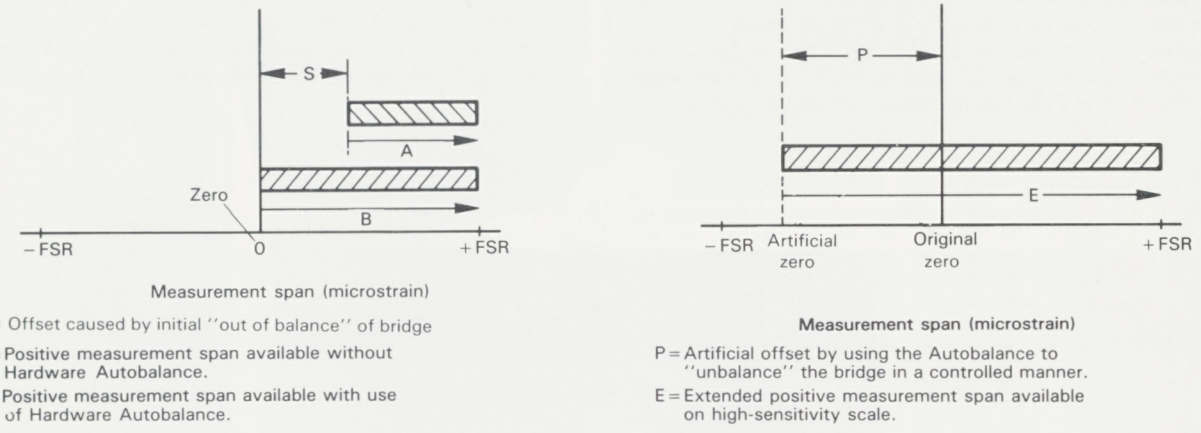
Argument Value	Energising Level
0	2×0 mA
1	2×1.0 mA
2	2×2.5 mA
3	2×5.0 mA

Table 3 Integration arguments

Argument Value	Integration Period
1	66 μs
2	1 ms
3	5 ms
4	10 ms
5	20 ms
6	40 ms
7	100 ms
8	200 ms
9	500 ms
10	1 s
11	2 s
12	4 s

Scale Number	Input Range FSR	Input Resolution (μV/bit at ADC)	Scale Length	Scale Number	Input Range FSR	Input Resolution (μV/bit at ADC)	Scale Length
0	+/−10.24 V	312.50 μV	+/−32 768	5	+/−320 mV	9.76 μV	+/−32 768
1	+/− 5.12 V	156.25 μV	+/−32 768	6	+/−160 mV	4.88 μV	+/−32 768
2	+/− 2.56 V	78.13 μV	+/−32 768	7	+/− 80 mV	2.44 μV	+/−32 768
3	+/− 1.28 V	39.06 μV	+/−32 768	8	+/− 40 mV	1.22 μV	+/−32 768
4	+/−640 mV	19.53 μV	+/−32 768	9	+/− 20 mV	0.61 μV	+/−32 768

Table 4 Nominal signal input ranges versus resolution for +/− 32 768 bits at the ADC



S = Offset caused by initial "out of balance" of bridge

A = Positive measurement span available without Hardware Autobalance.

B = Positive measurement span available with use of Hardware Autobalance.

P = Artificial offset by using the Autobalance to "unbalance" the bridge in a controlled manner.

E = Extended positive measurement span available on high-sensitivity scale.

Fig. 5 Hardware autobalance

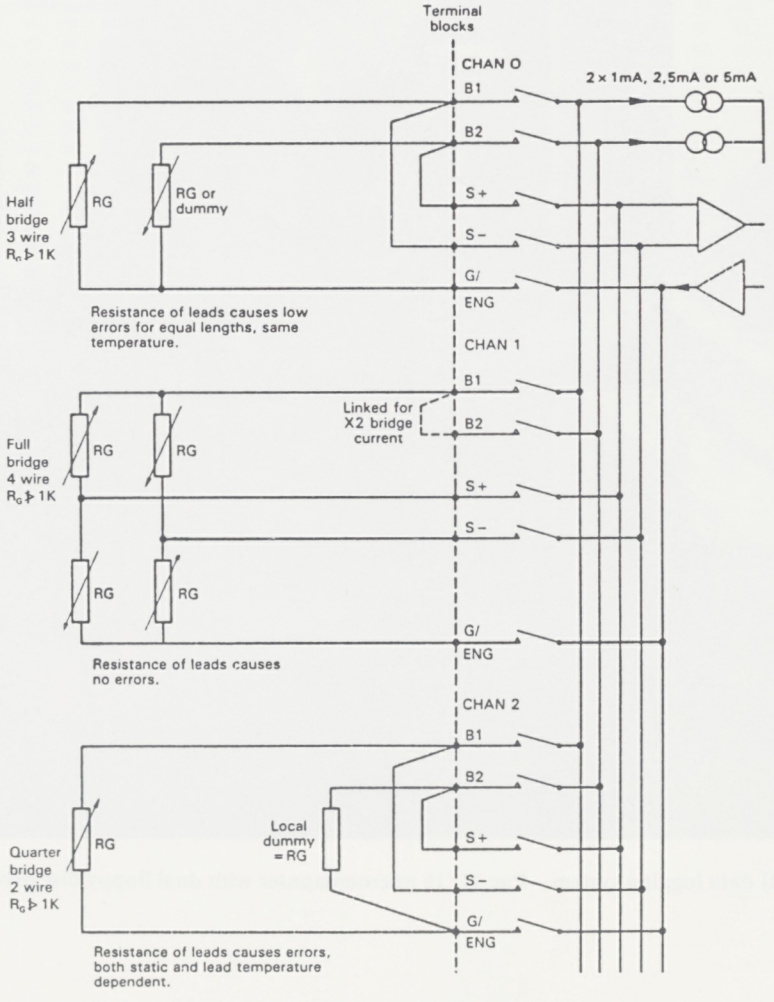


Fig. 6 Spectra data logger—typical strain gauge connections

3.4 Description of Compulog III System

The data logger system utilises a PAC 11/16 microcomputer system which is configured around the DEC LSI-11/2 microprocessor. The microcomputer handles the strain monitoring, data reduction and storage and control of peripheral input/output equipment. The equipment is large but transportable. Plate 8 shows the main cabinet surmounted by a floppy disc peripheral. The visual display unit acts as a system communicator and graphics reproducer and the printed output is produced on the page printer to the left of the picture. These parts of the system are able to operate remotely from the scanning cabinets. The total length of cable between the scanner cabinets and the control cabinet can be extended up to 10 000 metres. This is essential on large pressure vessels to enable the length of cable between the strain gauges and scanners to be kept to acceptable limits. Fig. 7 shows the cabinet capacities and available cable lengths. Plate 9 shows a 200 channel and a 300 channel scanner cabinet with an interconnecting cable. Strain gauge inputs are effected using 8-way plugs and spade connectors. The occupied sockets illustrated are being used for 100 dummy test channels.

The main cabinet houses the microcomputer, the controller and the system power supplies. The controller controls two main functions:

(a) The analogue measurement system.
(b) The data acquisition and control interfaces.

Both the analogue measurement system and the data acquisition system are fully programable enabling the user to select the measurement scale, the optimum scanning speed for minimum interference rejection and the sampling mode. Tables 5, 6 and 7 show the selection of these parameters available to the programmer.

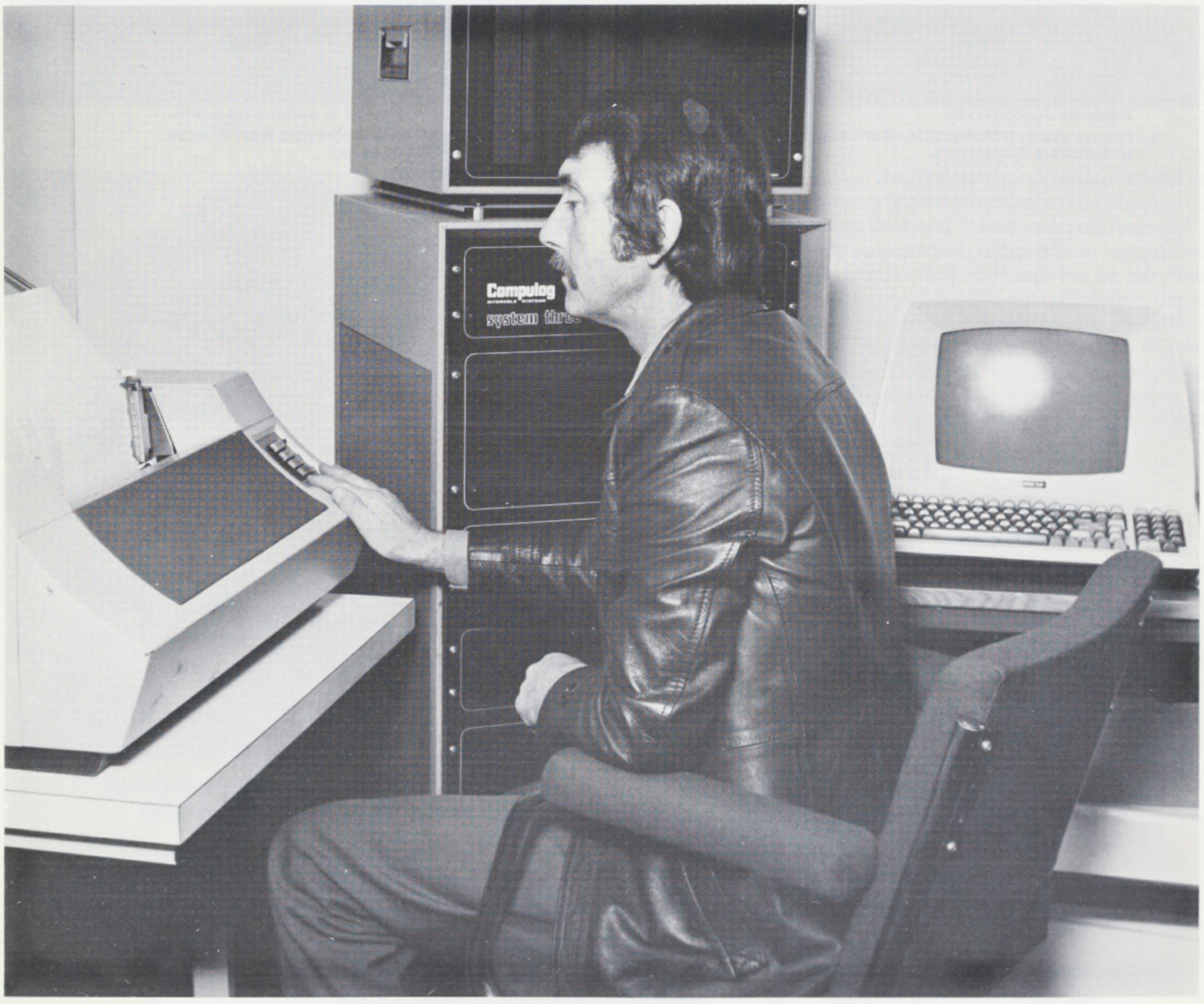


Plate 8 Compulog III data logging system—Pac 11/16 microcomputer with dual floppy disc drive, VDU and line printer

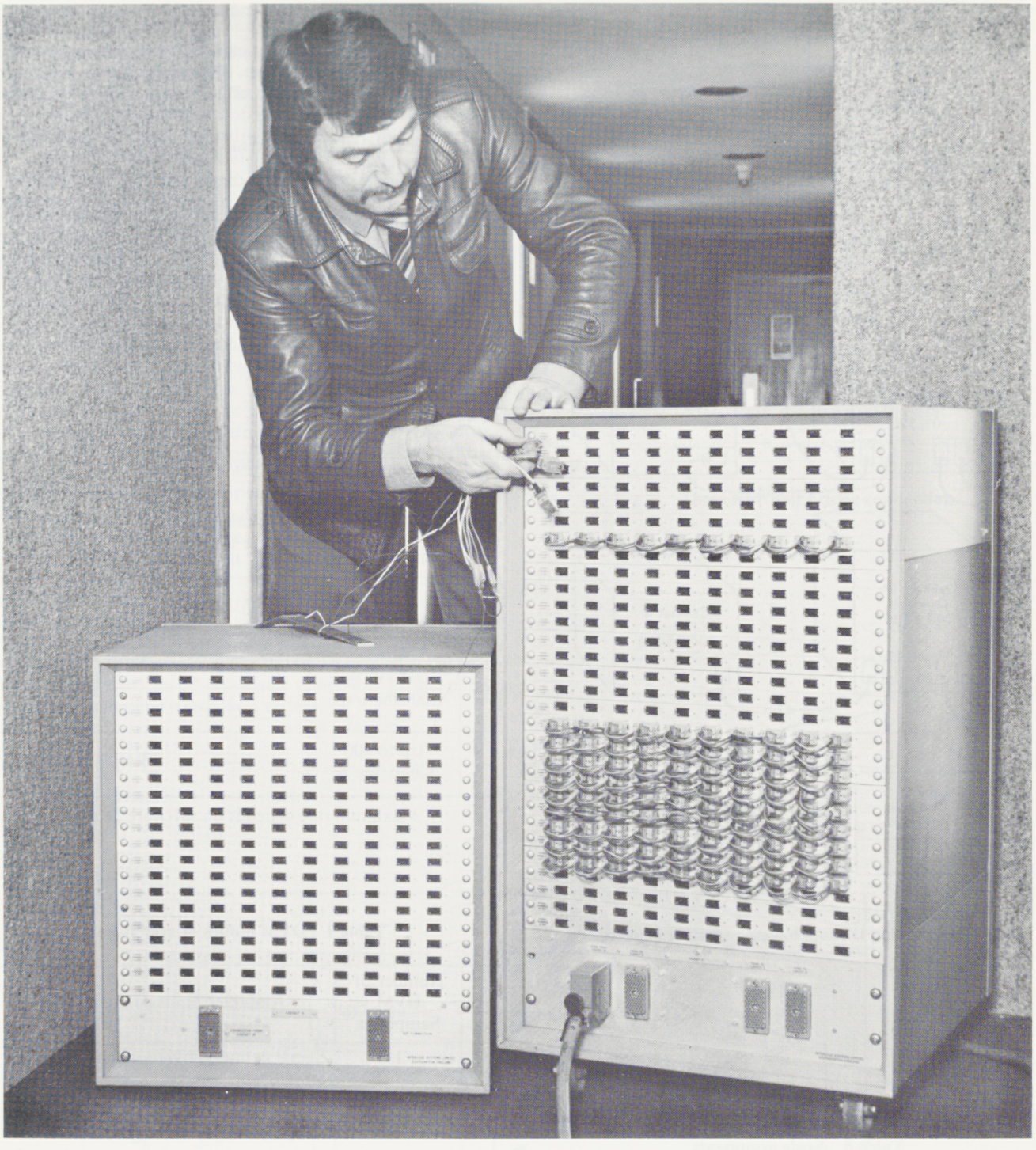


Plate 9 Compulog III data logging system—200 and 300 channel scanner units with signal conditioning amplifiers

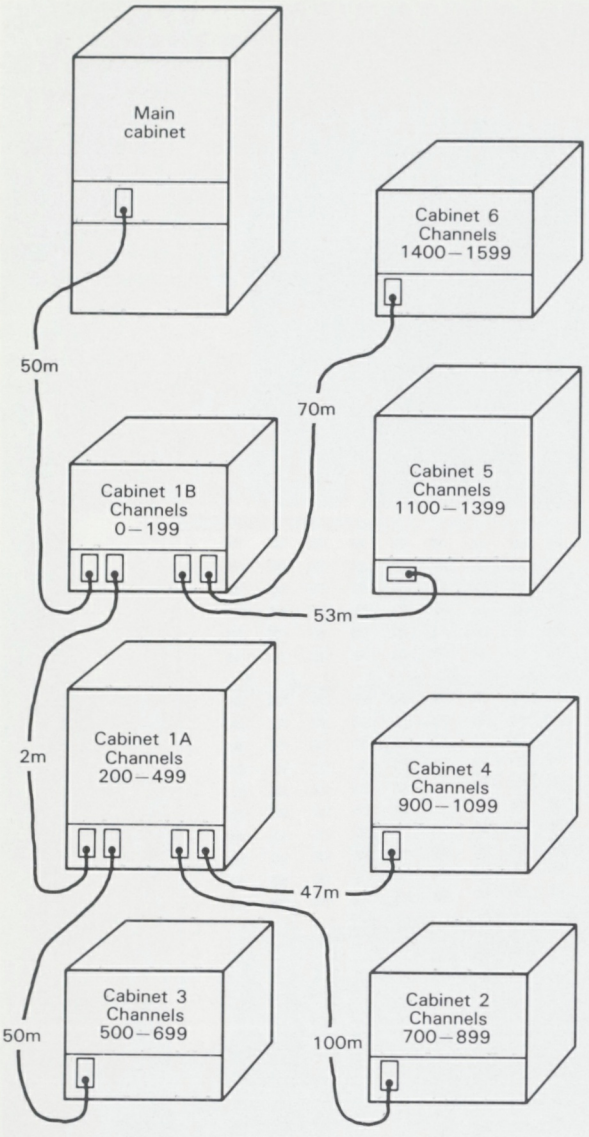


Fig. 7 Compulog III data logger—scanner capacities

Table 5 Scale arguments

A2	Voltage Measurement		Strain Measurement	
	Resolution Microvolts	Full Scale	Resolution Microstrain	Full Scale
0	0.3333333	10 mV	0.2	6 000
1	0.6666667	20 mV	0.4	12 000
2	1.666667	50 mV	1	30 000
3	3.333333	100 mV	2	60 000
4	6.666667	200 mV	4	120 000
5	16.66667	500 mV	10	300 000
6	33.33333	1.0 V	20	600 000
7	66.66667	2.0 V	40	1 200 000
8	166.6667	5.0 V	100	3 000 000
9	333.3333	10.0 V	200	6 000 000

NOTES:

1. The energising constant current for strain measurement is 6.666667 mA per arm. The values shown in Table 5 assume one active arm of 120 ohms with gauge factor 2.083.
2. FULL SCALE = 30 000 bits in the DVM.
3. The DVM maximum reading = + 32 767 to − 32 768.
4. The 7 significant digits used in the RESOLUTION column, do not imply the equivalent range to range accuracy. These figures may be used, in computer programs, to convert DVM reading to voltages, e.g. On scale 5 the output is 5261 bits

$$\therefore \text{voltage} = 5261 \times 16.66667 \times 10^{-6}$$
$$= 87.683 \text{ mV}.$$

Table 6 Scanning speeds

A3	DVM Sampling Rate	Recommended Scale Ranges	Remarks
1	$\frac{2}{3}$ of 50 Hz $33\frac{1}{3}$ Chan/sec	0—9	Integrating Mode Locked to 50 Hz
2	2 × 50 Hz 100 Chan/sec	4—9	50 Hz Cross Over Mode Locked to 50 Hz
3	Up to 300 Chan/sec #	7—9	Random sampling

Maximum rate depends on software delays

Table 7 DVM modes of operation

A4	Number of DVM Samplings	Amplifier input configuration
1	1	Signal connected via scanning to amplifier.
2	1	Scanner Open Circuit. Amplifier Input Short Circuit.
3	1	Strain gauge bridge connected via Scanner to Amplifier but energising disconnected.
4	2	1st Sample with A4 = 2. 2nd Sample with A4 = 1. DVM argument = difference.
5	2	1st Sample with A4 = 2. 2nd Sample with A4 = 1. DVM argument = difference.
6	2	Thermocouple measurement.
7	1	Signal connected via scanner amplifier but with ± 1.5 μA injected into input transducer via scanner.

A typical selection of program options for resistance strain gauges would be A2 = 2, A3 = 1, A4 = 5.

The measurement is carried out by an analogue to digital conversion process and with the sensitivity programed to scale 2, the full scale range of the measurement is 50 millivolts equivalent to strain resolution of 1 microstrain and full scale of measurement ±30 000 microstrain at 6.66667 mA energisation, 120 ohm strain gauges and a gauge factor of 2.083.

Reference to Table 6 shows the three programable operating modes of the digital voltmeter.

The mode A3 = 1 synchronises a single period integration to the period of the mains supply which operates the data logger. The period of a 50 Hz mains supply is 20 milliseconds to which is added 10 milliseconds for amplifier settling, thus the maximum scanning speed is 33⅓ channels/second. This is the optimum operating mode for the low level signals which are produced by resistance strain gauge circuits. The other two modes would not be used for pressure vessel work as the related sensitivity ranges would give an unacceptably low strain resolution.

The scanner contacting system utilises 8 reed relays per channel. Fig. 8 shows a gauge and dummy connected as a three wire half bridge to the scanner 8-way plug system. Fig. 9 shows the function of one channel of the reed relay contacts which simultaneously energise the bridge, apply the autobalance pattern and connect the output to the measuring system. The autobalance method used with Compulog III is effectively a 'remembered shunt resistance' which is set up and recalled for each individual channel that is switched across the gauge or its dummy gauge when a scan is made. It is very common to be measuring from a 3-gauge rosette at one location on a pressure vessel and Fig. 10 shows how one dummy gauge adjacent to a rosette is connected via a 5-wire cable to pre-wired triple plugs using a crimped spade connection system.

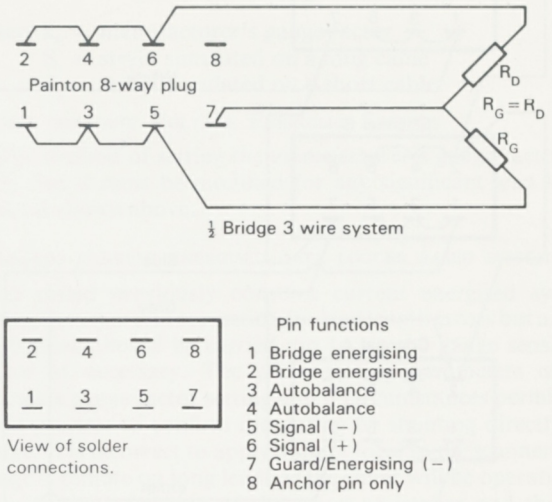


Fig. 8 Three wire half bridge connection

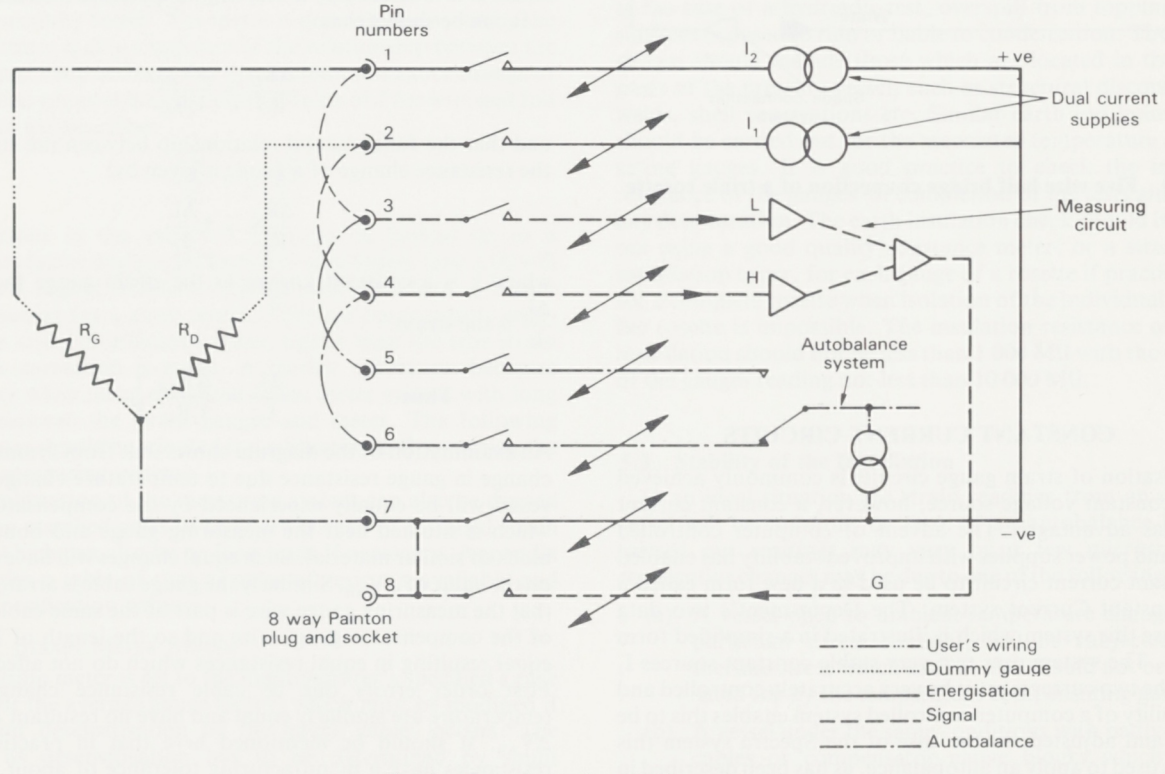


Fig. 9 One channel reed relay contact

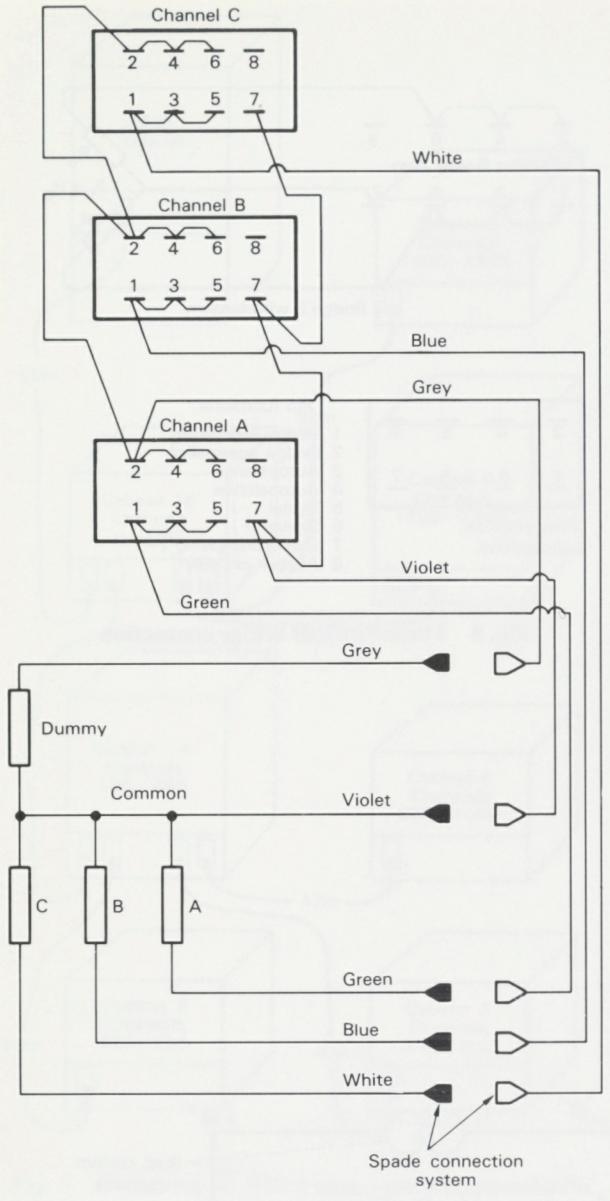


Fig. 10 Five wire half bridge connection of a triple rosette

4. CONSTANT CURRENT CIRCUITS

Energisation of strain gauge circuits is commonly achieved using a constant voltage source, however, a constant current source has advantages. The advent of computer controlled systems and power supplies with improved stability has enabled the constant current circuit to be used in a new form called a Dual Constant Current system. The Department's two data loggers use this system which is illustrated in a simplified form in Fig 11. The system uses two very stable constant sources I_1 and I_2. The two currents must be very accurately controlled and the flexibility of a computer controlled system enables this to be checked and adjusted. In the case of the Spectra system this facility is used to apply an autobalance, as has been described in section 3.3.2. In the case of the Compulog III system the currents are maintained equal within fine limits.

The main advantages of the system for pressure vessel work are:

(1) The elimination of 1st order errors which are due to the resistance of the cable between the strain gauge and the scanner.

(2) The ability of the systems to remember and apply autobalanced changes of this resistance due to temperature to each channel.

An additional advantage of the constant-current source is that it eliminates the inherent non-linearity of a constant voltage energised bridge circuit. It must be said, however, that this is not normally a problem with the bridge imbalances experienced in pressure vessel work when using 120 ohms resistance strain gauges.

Figure 11 shows the basic constant current circuit, the theory of which is as follows:

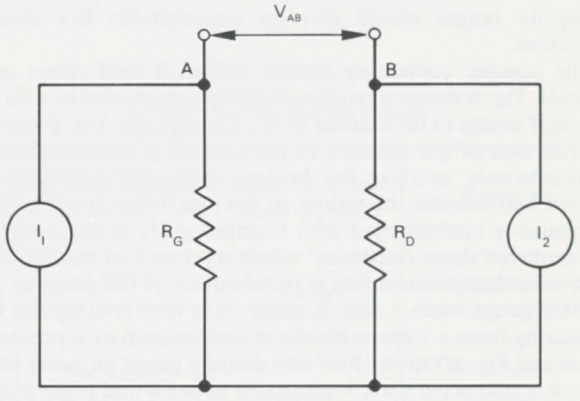


Fig. 11 Basic constant current circuit

R_G is the measuring gauge.
R_D is the dummy gauge which has the same nominal resistance.
I_1 and I_2 are the two current sources and the voltage between A and B is measured by a very high impedance instrument.
It can be shown that:

$$\frac{\Delta R_G}{R_G} = \frac{\Delta V_{AB}}{I_1 R_G}$$

and that the fundamental relationship between the strain and the resistance change of a gauge is given by:

$$\frac{\Delta R_G}{R_G} = k\frac{\Delta L}{L}$$

where k is a constant known as the strain gauge factor and $\frac{\Delta L}{L}$ is the strain.

Thus $$\frac{\Delta L}{L} = \frac{\Delta V_{AB}}{I_1 R_G} \cdot \frac{1}{k}$$

An examination of the diagram shows that from symmetry any change in gauge resistance due to temperature changes of the vessel will be equally experienced by the compensator gauge which is situated near the measuring gauge and bonded to a block of similar material. Such equal changes will have no effect on the value of ΔV_{AB}. Similarly the gauge cable is arranged such that the measuring gauge wire is part of the same cable as that of the compensator gauge wire and so the length of both are equal resulting in equal resistances which do not affect ΔV_{AB}. First order errors due to cable resistance changes with temperature are similarly equal and have no resultant effect on ΔV_{AB}. It should be mentioned here that in practice cable resistances have a manufacturing tolerance of about 5% and whereas initial inequalities of cable resistance are taken care of by the autobalance process, if a cable installation is subjected to

large changes of temperature then there may be a significant difference in changes of resistance between the measuring gauge wire and the compensating gauge wire, with subsequent second order errors in the value of ΔV_{AB}. In this case it will be necessary to measure the resistance of each wire and adjust the length to make all resistances equal. It has been necessary to do this for a series of tests on nuclear waste tanks where the tanks and, therefore, the cabling were subjected to changes of temperature of about 50°C.

5. CHECKING A STRAIN GAUGE INSTALLATION

It is sometimes necessary for an outport surveyor to witness a pressure test requiring strain measurements. In this case the following guidance notes are offered to enable the surveyor to satisfy himself as to the validity of the results. Generally it will not be possible, or necessary, to witness the installation of the complete system but there are a few basic tests which could be asked for once the installation was completed, i.e. calibration, earth resistance, identification of the channels, etc.

5.1 Calibration of an Installation

The calibration of a measuring system should be demonstrated before and after the test. This is most commonly achieved by shunt resistance strain simulation; when the selected shunt is applied across the calibrated strain gauge and the simulated strain is measured and compared with the expected strain value. Appendix D gives a table of shunt-calibration resistors with equivalent strain levels available commercially. The calibration resistors are made to give a resistance such that a convenient number of microstrain is simulated when used with a gauge of appropriate resistance. Any good quality resistor having a suitable value can be used and the simulated strain calculated using the expression:

$$\text{Simulated strain} = \left[\frac{\text{gauge resistance}}{\text{gauge resistance} + \text{shunt resistance}}\right] \cdot \frac{1}{k}$$

where k = gauge sensitivity factor.

There is often confusion about the application of a strain gauge sensitivity factor. The factor is normally provided by the manufacturer and is a measure of the relationship between the applied mechanical strain and the resultant resistance change of an installed gauge and has a nominal value of 2 for wire and foil resistance gauges, thus:

$$\frac{\Delta R}{R} = 2\frac{\Delta L}{L}$$

Variations in the value of 2.00 can be looked on as a sensitivity factor and gauges having a value higher than 2.00 will produce a higher resistance change and, therefore, a higher bridge output for a given strain. They are consequently over-sensitive and will indicate a strain higher than the true strain unless a correction is made. A further correction becomes necessary when using a manual strain meter system with long cables between the strain gauges and meter. The following procedures should be adopted for calibrating and correcting the various measuring systems.

The calibration of the measuring system can also be carried out using matched pairs of resistors instead of installed strain gauges which can also be on long leads if necessary. Appendix D includes a table of typical pairs of resistors available and shows specification values.

Manual Strain Meter System

The strain meter is set to the manufacturer's specified gauge factor (or the average gauge factor) which must be modified if significant desensitisation by the gauge cables occurs. The degree of desensitisation has to be determined by shunt simulation of a gauge (or equivalent resistor) on long and short leads using the strain meter with the gauge factor set to 2.00. Then the modified gauge factor setting will be given by:

$$k = \frac{k_m \cdot S_l}{S_s}$$

where k_m = manufacturer's gauge factor
S_l = strain simulated on a long cable
S_s = strain simulated on a short cable.

Other constant Voltage Energised Systems

The method of setting the manufacturer's gauge factor will vary, but it must be modified for any significant lead length error as shown above.

Constant current energised data logger based systems

As stated previously constant current energised systems normally require no correction for lead length errors but a shunt calibration should be carried out to set the gauge sensitivity factor as necessary. The programming parameters usually include a gauge factor setting and if circumstances permit, it is good practice to confirm the setting by shunting directly at a gauge. It is incorrect to apply a shunt local to the scanner if the gauge is remote on long leads as the shunt will be operating on a resistance consisting of the gauge resistance and the lead resistance.

Although it is permissible to use a dummy gauge or an equivalent good quality resistor in calibration operations with AC energised systems it should be noted that the resistor must be of a non-inductive type.

5.2 Strain Gauge Installation Earth Insulation Resistance

Strain gauges, however carefully installed, may even in a short time become partially or fully earthed, especially when exposed to the weather or when used underwater. The earth insulation resistance of the strain gauges should be checked at key stages of the installation and the results of such checks should be available for inspection. Even so, it is advisable, prior to the start of the measurements, to carry out a random check and in particular to check those gauges positioned in locations where contact with water is possible, i.e. water side of the vessel in the case of a hydraulic test, overspill from topping up and surfaces exposed to rain or liable to condensation. The selected gauges should include those which are located in the critical parts of the pressure vessel, such as structural discontinuities, welds, shell penetrations etc. Similar earth insulation checks should be carried out for the associated temperature compensating gauges. It is good practice to check the insulation resistance of the gauges on completion of the tests and to note any deterioration. The earth insulation check should be carried out using a good quality resistance meter, or a strain gauge installation tester, for each gauge of a rosette if practicable, or for a complete rosette when isolation of the individual limbs of the rosette is impossible. The insulation resistance of a good installation should not be less than 1 000 MΩ with the majority of the gauges reading not less than 10 000 MΩ.

5.3 Stability of the Installation

In an ideal situation the strain readings from an unloaded vessel will be constant, or zero. If an autobalance has been carried out readings may vary by a few microstrain but consecutive changes may be due to one of the following reasons:

(a) A vessel open to ambient temperature changes and in particular direct sunlight, will be subjected to real thermal stress which cannot and should not be compensated for by the temperature compensating gauges.

(b) A vessel under the same conditions with badly matched cables or compensator gauge blocks which are not following the temperature of the shell in way of the gauge will give rise to zero drift.

(c) Drift of an individual channel may be due to a badly installed gauge, faulty electrical connections or scanner contacts, or poor insulation resistance to earth.

5.4 Strain Gauge Channel Identification

The strain gauge channel identification should be carried out to ensure that all connections and their identifications agree with the locations of the gauges to which they relate. For some installations the checks can be carried out immediately prior to the start of the tests but, in cases where waterproofing and protection against mechanical damage will be applied, an identification check at the earliest possible stage of the installation cannot be overemphasised.

The identification of all gauges is a tedious task and in some cases, such as large data logger based installations, is impracticable for an outport surveyor but, regardless of the size of the installation, the gauges in the most critical locations of the vessel must be checked.

The most effective and simplest method is to apply direct pressure on each gauge using a cotton bud. Even gentle pressure will result in the output of detectable strain at the measuring instrument.

In cases where the surveyor is faced with a completed installation and where the gauges are inaccessible due to waterproofing or another type of protection, identification becomes difficult. For vessels with comparatively thin shells a steady pressure applied to the shell in close proximity of the tested gauge may produce the required result, but in this case the complete rosette or even adjacent rosettes may be strained.

6. SOME THEORETICAL CONSIDERATIONS

6.1 Basic Expressions

The evaluation of strain measurements is based on the computation of the Cartesian and principal stresses using comparatively simple mathematical expressions. The derivation of the basic relationship between strain in the general direction and orthogonal and shear strains is given in Appendix E. The equation for strain in a general direction contains three unknowns, namely ϵ_x, ϵ_y and γ_{xy}. The unknown strain levels in Cartesian co-ordinates and the shear strain can be evaluated if the strain in three general directions at location is known. The value of ϵ_α in three directions can be measured by the limbs of a triple strain gauge rosette. The above three unknowns can then be computed using the matrix algebra as follows:

$$\begin{bmatrix} A \\ B \\ C \end{bmatrix} = \begin{bmatrix} 1 & \cos 2\alpha_0 & \sin 2\alpha_0 \\ 1 & \cos 2\alpha_1 & \sin 2\alpha_1 \\ 1 & \cos 2\alpha_2 & \sin 2\alpha_2 \end{bmatrix}^{-1} \begin{bmatrix} \epsilon_{\alpha 0} \\ \epsilon_{\alpha 1} \\ \epsilon_{\alpha 2} \end{bmatrix}$$

where: $A = (\epsilon_x + \epsilon_y)/2$

$B = (\epsilon_x - \epsilon_y)/2$

$C = \gamma_{xy}/2$

In the above matrix the angles α_0, α_1 and α_2 represent angular displacements of each limb of a triple strain gauge rosette from a chosen reference axis. In practice it is usual to locate the rosette such that one limb coincides with the reference. The most commonly used strain gauge rosettes are those with the following limb angular positions:

(a) $\alpha_0 = 0°$; $\alpha_1 = 45°$; $6\alpha_2 = 90°$

(b) $\alpha_0 = 0°$; $\alpha_1 = 60°$; $6\alpha_2 = 120°$

(c) $\alpha_0 = 0°$; $\alpha_1 = 120°$; $6\alpha_2 = 240°$

The values of A, B and C expressed in terms of α_0, α_1 and α_2 for all the above rosette configurations are given in Appendix F.

To obtain the maximum and minimum strain values, the general equation for ϵ_α is differentiated with respect to α to obtain the angle α_p of the maximum principal strain:

$$\tan 2\alpha_p = \gamma_{xy}/(\epsilon_x - \epsilon_y) = C/B$$

Substituting the value of α_p into a general equation the magnitudes of principal strains can be calculated:

$$\epsilon_{max} = A + \sqrt{B^2 + C^2}$$

$$\epsilon_{min} = A - \sqrt{B^2 + C^2}$$

and the maximum shear strain is:

$$\gamma_{max} = \sqrt{B^2 + C^2}$$

Having defined the magnitudes of the principal strains it is possible to calculate principal stresses from the following equations:

$$\sigma_{max} = (E/(1-\mu^2)) * (\epsilon_{max} + \mu\epsilon_{min})$$

$$\sigma_{min} = (E/(1-\mu^2)) * (\epsilon_{min} + \mu\epsilon_{max})$$

$$\tau_{max} = (E/(2*(1+\mu))) * \gamma_{max}$$

The Cartesian stresses can be calculated using the above expression but substituting Cartesian strains for principal strains:

$$\sigma_x = (E/(1-\mu^2)) * (\epsilon_x + \mu\epsilon_y)$$

$$\sigma_y = (E/(1-\mu^2)) * (\epsilon_y + \mu\epsilon_x)$$

$$\tau_{xy} = (E/(2*(1+\mu))) * \gamma_{xy}$$

The above expressions can be used to calculate strains and stresses using the results from rosettes on both internal and external shell surfaces.

An example of strain distribution around a point of measurement in a theoretical uniaxial field is shown in Fig. 12 where the direction of the maximum principal strain coincides with the x-axis. In this case the minimum principal strain is equal to the Poisson's effect only and lies in a plane displaced 90 degrees from the x-axis.

In the more general case of a biaxial field (Fig. 13) the direction of the principal strains may not be so clearly defined. The strain field like the one indicated in the figure could be found on both external and internal surfaces of the shell of a pressure vessel.

In the simplest case the principal strains on the internal and external surfaces would be equal in their magnitude, sense and direction and the stress through the shell thickness would be constant and equal to the surface stresses.

In practical cases the magnitudes of the principal strains on the external and internal surfaces of the shell differ. The direct strain acting on the shell cross section is combined with the bending strain and it is this overall strain level which is measured. The decomposition of the calculated overall stress level to its membrane and bending stress components can be carried out using the following expressions:

for membrane stress: $\sigma_M = (\sigma_E + \sigma_I)/2$

for bending stress: $\sigma_B = (\sigma_E - \sigma_I)/2$

where σ_E and σ_I are external and internal stresses respectively

The above expressions are valid if the surface principal planes coincide. In cases where the principal planes on the surfaces of the shell do not coincide the expressions cannot be used and the following calculation procedure has to be adopted. The maximum and minimum membrane and bending stresses occur in the following planes:

membrane stress: $\varphi_M = 0.5 * \arctan (C_I + C_E)/(B_I + B_E)$

bending stress: $\varphi_B = 0.5 * \arctan (C_I - C_E)/(B_I - B_E)$

where B_I, C_I, B_E and C_E are defined as above for internal and external surfaces respectively.

Having established the directions of the maximum stresses, the surface and through thickness components are calculated using the general strain equation and equations for membrane and bending stresses. It should be noted that in this case the maximum membrane and bending stress planes do not coincide and that the shear stress in the shell may be of a considerable magnitude.

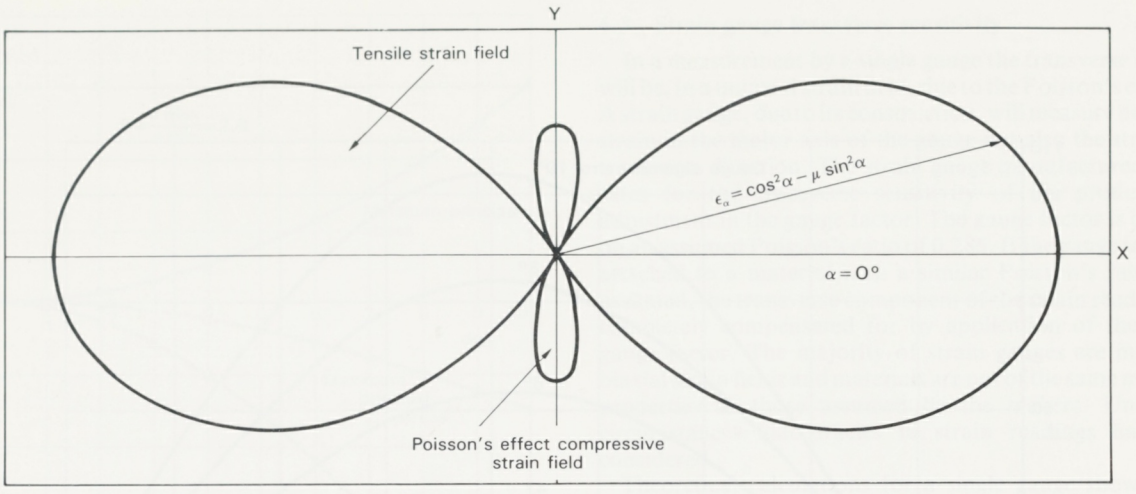


Fig. 12 Uniaxial strain field



Fig. 13 Biaxial strain field

6.2 Strain gauge misalignment

The expressions given in section 6.1 assume that no misalignment of a T gauge or limbs of a rosette from the intended direction of measurement is present. The misalignment of a gauge from the reference axis can cause measurement errors which will affect the accuracy of the results. A single gauge positioned within a uniaxial strain field (Fig. 12) will, when misaligned from the intended direction of measurement, indicate with varying degrees of accuracy depending on its position with respect to the maximum principal plane. The maximum error will occur when the gauge is displaced 45 degrees from the principal plane. In this region of the strain field, as the diagram shows, the strain magnitude changes rapidly. A similar area of high strain gradient is at 90 degrees to this position. The error in the strain readings in percent can be calculated from the following expression:

$$\epsilon_E = \frac{\epsilon_{(\varphi \pm \beta)} - \epsilon_\varphi}{\epsilon_\varphi} \times 100\ (\%)$$

$$\text{also } \epsilon_E = (\cos 2(\varphi \pm \beta) - \cos 2\varphi)/(R_E + \cos) * 100(\%)$$

$$\text{where } R_E = (\epsilon_{max} + \epsilon_{min})/(\epsilon_{max} - \epsilon_{min})$$

and ϵ_φ is the strain in the intended direction of measurement,

$\epsilon_{\varphi \pm \beta}$ is the strain in the misaligned direction,

ϵ_{max}, ϵ_{min} are the principal strains.

A typical example of a percentage error due to a gauge misalignment in a uniaxial strain field is shown in Fig. 14. The above approach can be extended to the evaluation of errors for T-gauges or the misalignment of individual gauges within a rosette. In the case of a T-gauge the percentage error in calculated stress due to a misalignment of the complete rosette is given as follows:

$$E_{\sigma(max)} = (1 - Q)/2Q * (1 - \cos 2\beta) * 100(\%)$$

$$E_{\sigma(min)} = (Q - 1)/2 * (1 - \cos 2\beta) * 100(\%)$$

$$E_{\tau(max)} = -(1 - \cos 2\beta) * 100(\%)$$

where $Q = \sigma_{max.}/\sigma_{min.}$ and $\sigma_{max.}$, $\sigma_{min.}$ and $\tau_{max.}$ are the maximum and minimum principal stresses and shear stress respectively. The errors due to the varying degree of misalignment are shown in Figs. 15 & 16.

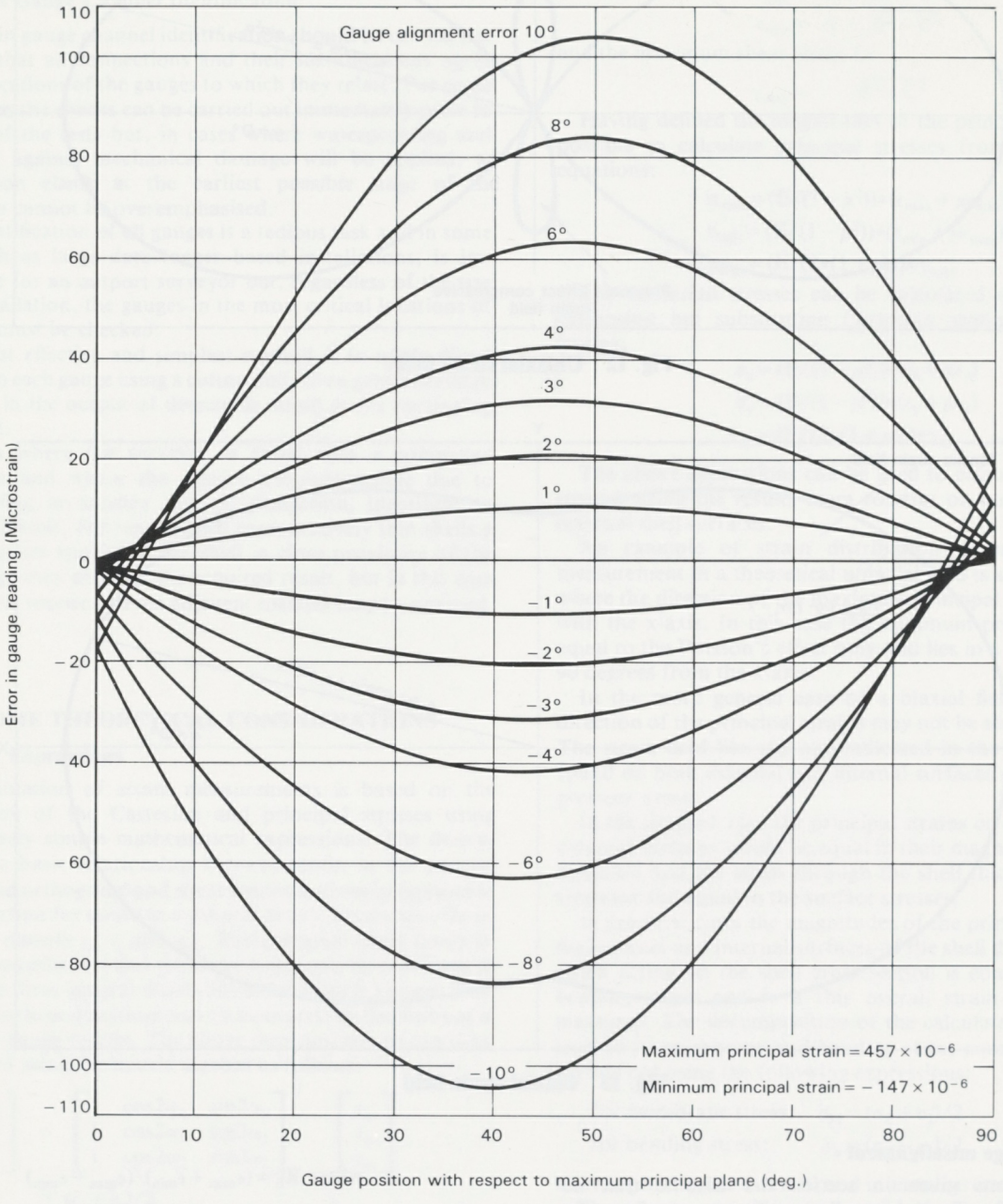


Fig. 14 Error in gauge readings due to gauge misalignment

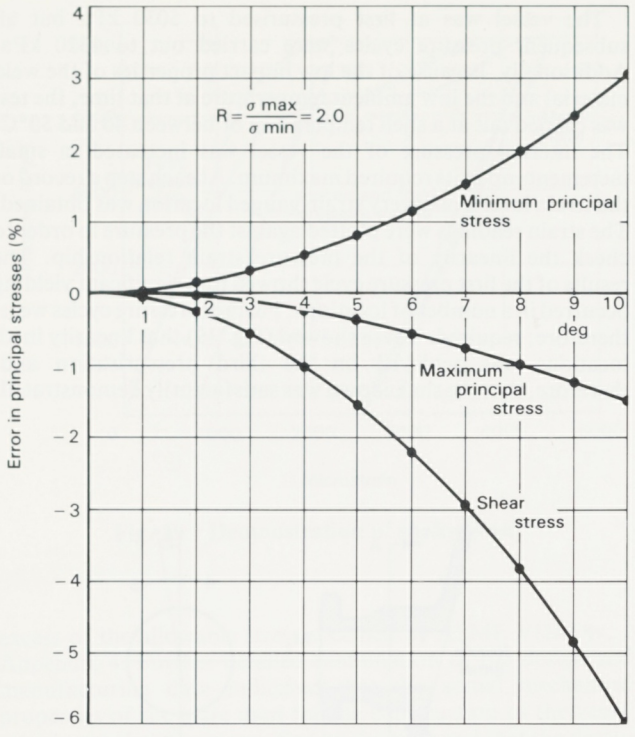


Fig. 15 Error in principal stresses due to misalignment for a T-gauge rosette

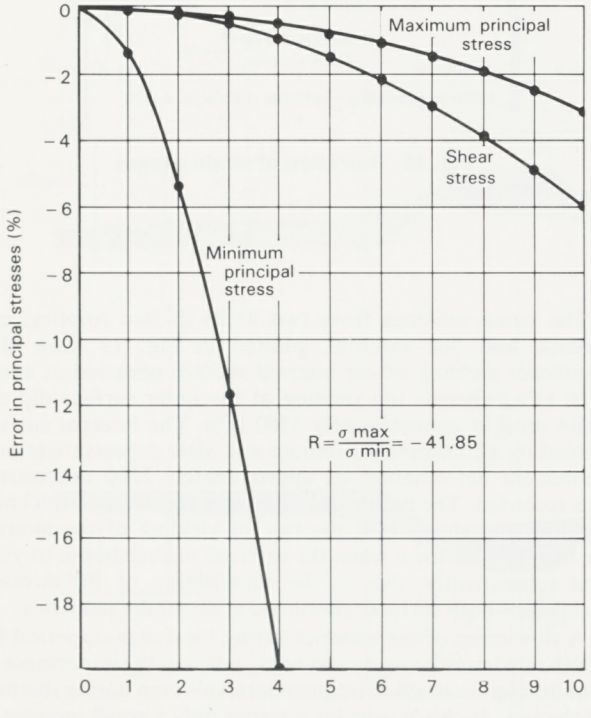


Fig. 16 Error in principal stresses due to misalignment for a T-gauge rosette

6.3 Strain gauge transverse sensitivity

In a measurement by a single gauge the transverse sensitivity will be, in a uniaxial strain field, due to the Poisson's effect only. A strain gauge, due to its construction, will measure not only the strain in the major axis of the gauge but also the strain in the transverse direction. The strain gauge manufacturer compensates for the transverse sensitivity of his product by an adjustment in the gauge factor. The gauge factor is also based on an assumed Poisson's ratio of 0.285. If the gauge is therefore attached to a material with a similar Poisson's ratio to that assumed, the transverse component of the strain reading will be completely compensated for by application of the specified gauge factor. The majority of strain gauges are mounted in biaxial strain fields and materials are not of the same mechanical properties as those assumed by the makers. Under those circumstances inaccuracies in strain readings have to be considered.

Theoretical calculations for a single gauge show that the maximum error occurs with the gauge positioned in the maximum principal strain direction and when the maximum and minimum principal strains are equal in magnitude and sense. Typically the measured strain could have an error of up to 3% of the maximum strain.

The usual application of the gauges in T or three limb rosette configurations allows determination of true strain. In case of T-gauges the true strain in the direction of the strain gauge limbs can be calculated as follows:

$$\bar{\epsilon}_x = (1 - \mu_o k)(\epsilon_x - k\epsilon_y)/(1 - k^2)$$
$$\bar{\epsilon}_y = (1 - \mu_o k)(\epsilon_y - k\epsilon_x)/(1 - k^2)$$

where k is the gauge transverse sensitivity,

μ_o Poisson's Ratio assumed by the gauge manufacturer,

ϵ_x, ϵ_y strain levels measured by gauges in x, y directions respectively.

7. PRESSURE VESSEL TESTING

7.1 Pressure Vessel Shakedown

A measurement frequently carried out by TID is pressure vessel shakedown. The object of the test is to demonstrate, using a strain indicating technique, that the vessel behaves in an elastic manner under the required test pressure. The standards in general specify the requirements for shakedown tests in the proof hydraulic test section of the code. The test is applied whenever a doubt exists as to the integrity of the vessel as a whole or, more often, of a critical area only. During this test the stress levels are not the major criterion. The behaviour of the vessel is judged on the basis of the linearity of the pressure/strain relationship.

The shakedown process can be illustrated in an idealised stress-strain diagram as shown in Fig. 17. The material is assumed to behave in either an elastic or perfectly plastic manner. Due to an applied load an elastic deformation occurs at some point in the vessel's shell from O to A and plastic irreversible deformation from A to B. At point B the stress is sufficiently reduced by the plastic deformation to be in equilibrium with internal resisting stresses in the shell. When the load is reduced to its original value the stresses recover along the line BCD. The elastic portion from C to D represents prestressing in compression of the permanently strained fibres in such a way that the next operating cycle from D to B lies entirely in the elastic range. The shakedown load is the maximum self-limiting load that, when applied to a vessel, will on removal leave such built-in internal residual stresses that any subsequent application of the same or smaller load will cause only elastic stresses in the vessel. If the plastic deformation from

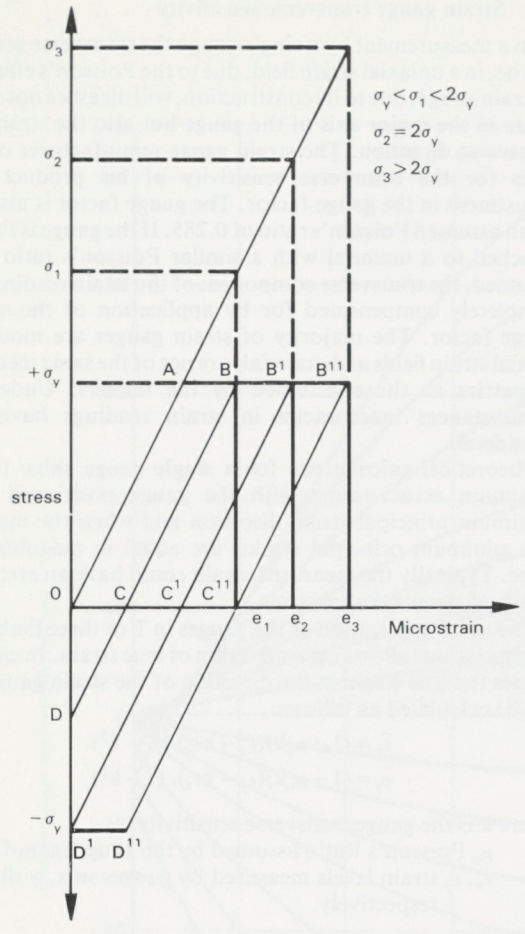


Fig. 17 Idealised stress-strain diagram demonstrating shakedown

A to B^{11} is too large then when the load is removed and the structure returns to the original state, a compressive yield from D^{11} to D^1 is introduced. At the next operating cycle the stress is in the plastic range again causing a further increase in the plastic strain and an increase in the deformation thereby, initiating ratcheting.

An example of a successful demonstration of the shakedown and subsequent acceptance of the vessel by the Society can be illustrated by the following case history.

The vessel, constructed to the ASME code, was a vertical cylindrical pressure vessel intended for the petrochemical industry. The manufacturer's calculations for the top end conical/cylindrical transition and shell penetrations were reviewed and revealed some serious omissions in the modelling of the structure. The calculations carried out by the Society indicated high stresses in the transition region and around the shell penetrations in that area. It was agreed by all parties concerned to resolve the matter by comprehensive stress measurements in all areas of doubt and the acceptance of the vessel was conditional upon a satisfactory demonstration of the shakedown

The location of the strain gauges in the critical areas of the vessel and in reference locations away from the shell penetrations and structural discontinuities is shown in Fig. 18. In total 22 areas were strain gauged using rectangular rosettes as well as T-gauges.

The vessel was at first pressurised to 5030 kPa but all subsequent pressure cycles were carried out to 4320 kPa. Additionally, because of the low impact properties of the weld material and the low ambient temperature at that time, the test was carried out at a shell temperature of between 40 and 50°C. The internal pressure of the vessel was increased in small increments up to its required maximum. At each step a record of the strain level from every strain gauged location was obtained. The strain readings were plotted against the pressure in order to check the linearity of the pressure/strain relationship. The results of the first pressure cycle showed that significant yielding occurred in a number of locations. Further pressure cycles were, therefore, required. These showed (Fig. 19) that linearity in all locations was achieved on the third pressurisation and, therefore, that the shakedown was satisfactorily demonstrated.

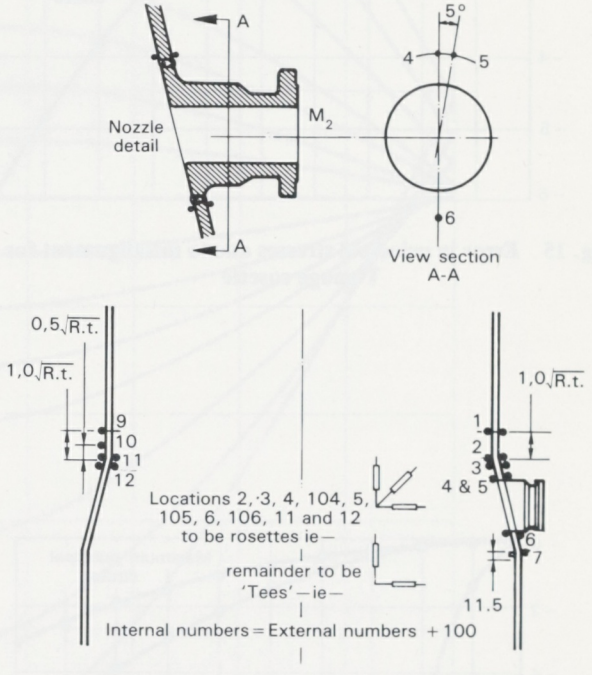


Fig. 18 Location of strain gauges

The strain readings from two limbs of two rosettes, one internal and one external, plotted in Fig. 19 show that significant yielding of the internal surface occurred at about 3750 kPa, whereas the yielding of the outer surface did not begin until at approximately 4500 kPa. The internal surface yielded by a considerable amount and after depressurisation a permanent deformation of approximately 2500 microstrain was recorded. The figure also illustrates the through thickness yielding and shows how the rate of yielding of the internal surface slowed down when the external surface began to yield and subsequently, due to the equalisation of the stresses, yielding of both surfaces continued at about the same rate.

A slow creep of the material during the one hour period for which maximum pressure was held, indicates the importance of monitoring the strain at frequent intervals even during this part of the test. In this particular instance only a small increase in strain level was noted.

The subsequent stress analysis carried out using the results of the measurements showed that the stress levels measured in the region of the cone/cylinder junction above the manhole were in

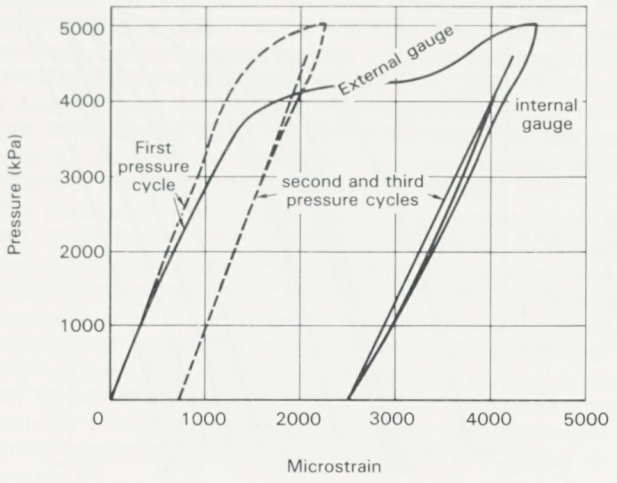


Fig. 19 Demonstration of shakedown

excess of the allowable stress specified by ASME VIII Div. 2 Appendix 4. Further detailed examination of the design and manufacturing data indicated that the actual mechanical properties of the plate used for the construction of the vessel were better than those specified by the code and that the design temperature of the vessel was set unrealistically high.

Based on the above findings and the satisfactory demonstration of shakedown, the vessel was accepted.

The majority of vessels tested by TID achieved shakedown condition within a specified number of pressure cycles. An example of a case where shakedown was not demonstrated was the study and measurement of a full scale prototype undersea pipe repair module of novel design.

Following the calculations carried out using the finite element model method of analysis, the full scale assembly of the repair module was strain gauged. In total some 113 rectangular rosettes and 51 axial chain gauges in five positions were used (*see* Fig. 20). The object of the tests was to confirm that the finite element model of the repair configuration was representative and that the stress levels calculated by the theory could be correlated to the experimental results, and also to demonstrate the model shakedown.

Three types of loading were applied to the test rig, namely internal pressure, bending moment and axial compressive load. The tests were carried in two stages, firstly up to 75% of the maximum of each load, in order to provide data for correlation with the results of the finite element analysis, and then internal pressure and axial load tests to maximum design loading to demonstrate the shakedown of the model.

The initial results of the tests indicated satisfactory correlation with the theoretical calculations (*see* Fig. 21).

The shakedown test for the internal pressure was carried out increasing the pressure in small increments at each of which strain readings were obtained. The plot of the pressure vs. strain shows that the first application of the pressure resulted at some locations in a certain amount of local yielding. The second pressurisation cycle demonstrated that the pressure/strain linearity was achieved and it was, therefore, concluded that for this type of loading shakedown was attained.

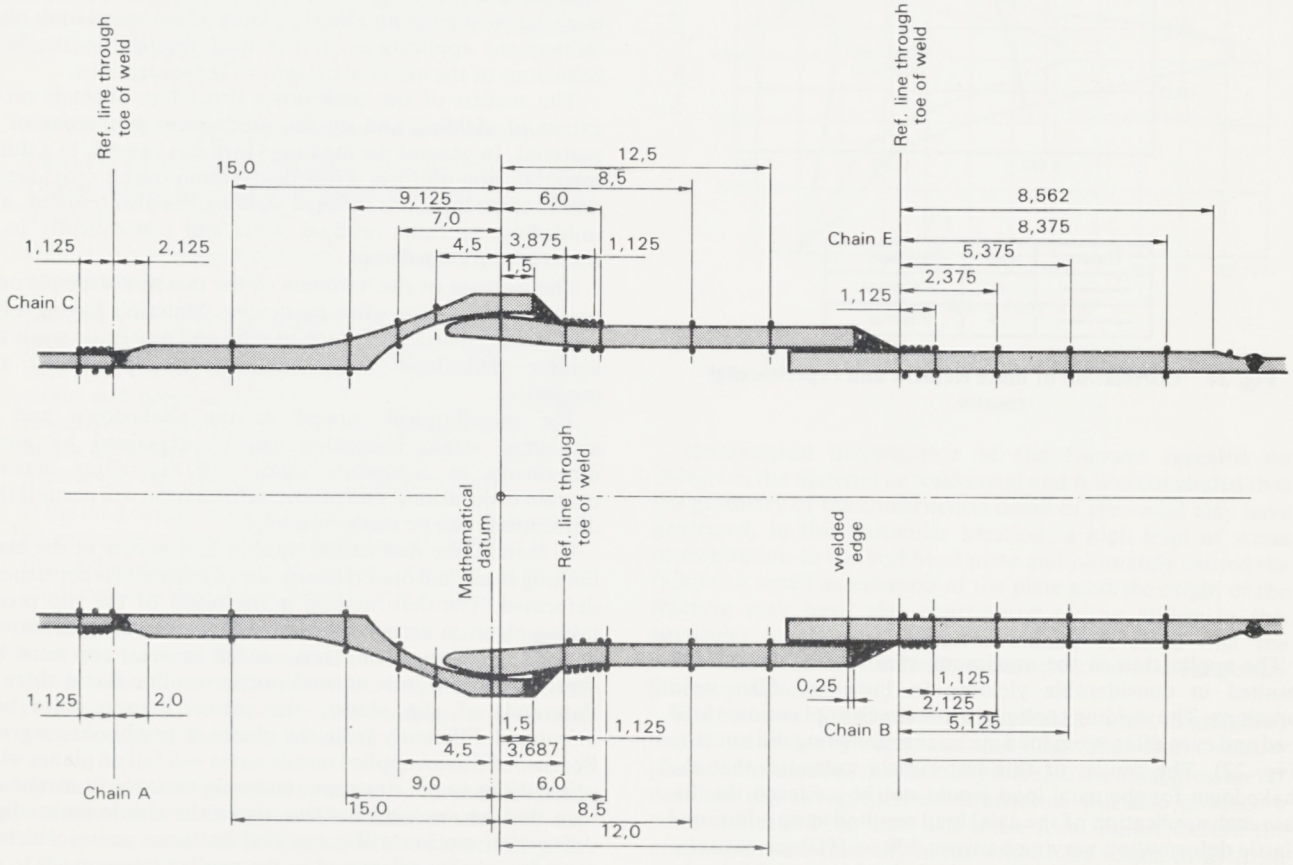


Fig. 20 Allocation of strain gauges for comparison with theoretical analysis

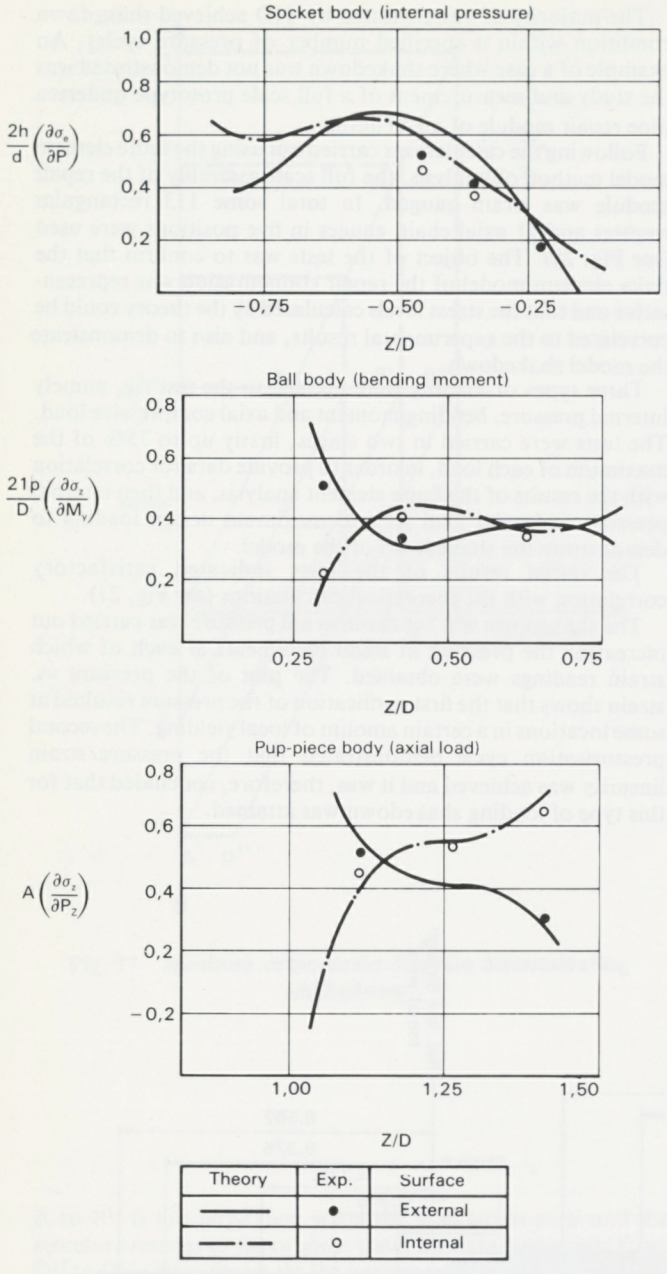


Fig. 21 Correlation of finite element and experimental results

The application of the maximum axial load of 8190.5 kN resulted in considerable yielding in butt and fillet weld junctions. The yielding took place after each application of the load and even after seven load cycles the ratcheting did not stop (Fig. 22). The results of this test clearly indicated that the shakedown for the axial load would not be achieved. In this case each application of the axial load resulted in an additional plastic deformation varying between 500 to 1500 microstrain.

Further tests at reduced loads helped to establish the maximum axial load at which the linear behaviour of the model were demonstrated. The load at which the linearity was eventually accomplished was 5493.6 kN.

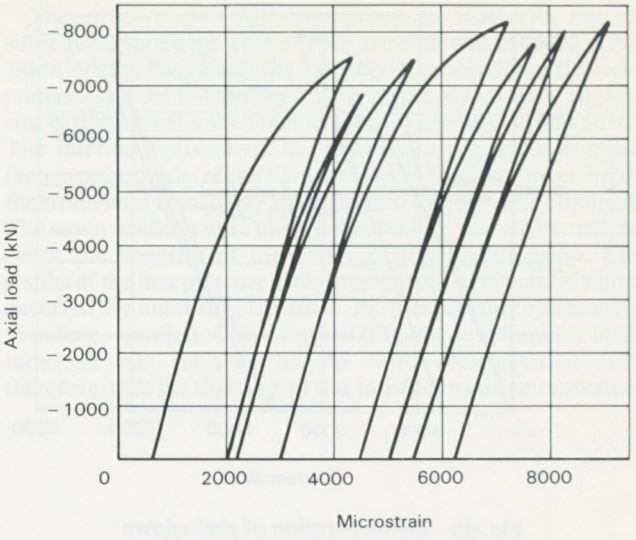


Fig. 22 Application of subsequent loads causing ratcheting

On the basis of the theoretical calculation and the results of the experimental tests the proposed repair design was considered satisfactory with the exception of the butt and fillet weld geometries which were unable to withstand the design axial loads. As a result of these theoretical calculations, experimental tests and subsequent photoelastic tests of the various configurations of the weld detail a modification to the butt and fillet weld geometry was recommended.

The shakedown tests illustrated in the above two examples indicate that the stress levels in some local areas exceeded the material yield point and local yielding of the vessel took place. Subsequent applications of the load resulted in the linear behaviour of the material in some of these locations.

The success of the shakedown procedure depends on the extent of yielding and on the mechanical properties of the material. In general the loading which has caused, in a ductile material, non-uniform stress distribution over a cross-section and in some locations induced yielding has also resulted, after unloading, in some residual stress and consequently in the material work-hardening.

The increase of the hardness of the material depends on its susceptiblility to the work-hardening. Materials having a high rate of work-hardening, such as mild and austenitic steels may achieve shakedown sooner than materials without such properties.

The metallurgical aspects of the shakedown and the associated strain hardening can be explained by atomic movements in crystalline solids. All crystalline materials contain dislocations, and plastic deformation will occur if these dislocations can be made to move.

In metals, the dislocation motion first occurs at the elastic limiting stress and once it has occurred the metal is permanently deformed. The deformation is the result of the slip process taking place on certain crystalographic planes which move in definite directions. The stress needed to cause slip must be a shear stress and in a normal polycrystalline metal there are thousands of slip planes, the planes in one grain being orientated differently from the planes in neighbouring grains. Because of this an applied tensile stress will fall on planes whose orientations to the stress are randomly variable. It can be seen then that on applying a stress above the elastic limit, slip or dislocation motion will occur first on those planes which are most favourably orientated to the applied stress.

Once slip has taken place on the most favourably orientated planes, dislocation multiplication occurs, and eventually dislocation motion on that plane stops because so many

dislocations are generated that their stress fields begin to interact with each other. Further slip must then occur on less favourably orientated planes and this requires a higher value of applied stress to give the required higher shear stress. In effect, the metal becomes capable of carrying higher stresses and this is the effect termed work or strain hardening. The process results in an increased elastic limit or yield strength and hardness of the material but decreases the ductility.

The shakedown procedure and strain gauging can be used to carry out mechanical stress relief of pressure vessels. It should be noted that considerable strain re-distribution during the first or even the second loading cycle will take place. The mechanical stress relief, with the exception of a small amount of the work-hardening, will not result in changes in metallurgical conditions of the weld area. It is, therefore, emphasised that thermal stress relief should always be applied where this is required and practically possible and that only in special cases and under controlled conditions should the mechanical stress relief be carried out.

The following shakedown procedure can be applied where mechanical stress relief is required and this procedure has been successfully carried out by TID for a number of years.

7.2 Shakedown Procedure

The shakedown and mechanical stress relief tests should be carried out using a strain monitoring technique which in a majority of the cases should employ electrical resistance strain gauges. The strain gauges should be positioned on locations where high strain levels are likely to occur, i.e. next to the welds, welded intersections, shell penetrations, vessel supports etc. The strain gauges should be three element rosettes and should be positioned outside and inside the shell opposite each other in all locations of interest. Such configurations will then allow calculation of principal strains, stresses, directions of principal planes and membrane and bending stresses. The following procedure should be adopted:

1. Obtain strain gauge zero readings with vessel empty.
2. Fill the vessel gradually and ensure that all air is expelled. During filling obtain strain gauge readings at suitable intervals.
3. Obtain strain gauge readings with the vessel full but unpressurised.
4. Increase the hydraulic pressure to the maximum test pressure at 10% increments recording the strain levels at each step. During this part of the test, plot the maximum strain and pressure readings on abscissa and ordinate respectively, ensuring that the plot remains linear. If a major departure from linearity is in evidence, reduce the pressure to zero and begin a new pressure cycle.
5. If the load/strain relationship is non-linear at first, up to six pressure cycles can be carried out. If linearity is not then achieved determine by further pressure cycles the load level at which elastic behaviour is realised.
6. Having demonstrated linearity in all strain gauge locations increase the pressure to maximum and hold this pressure for a minimum of two hours during which period at least two further strain readings at all strain gauge locations should be obtained.

During the above tests principal stresses should be calculated and at no time should the general membrane stress in the reference location exceed 90% of the minimum specified yield stress of the material.

The above procedure is specifically written for a hydraulic test but it may also be applied with small modifications to pneumatic tests. It also should be remembered that when examination of the vessel under test pressure is undertaken the pressure, particularly in case of a pneumatic test, should be reduced by 10%.

7.3 Test to Destruction

Recent work carried out on a scale model (1:3) of an LNG/LPG storage tank enveloped all aspects of the testing discussed so far. In addition to the shakedown test, a mechanical stress relief test and a test to destruction were also carried out. The object of the tests was to correlate the results of the finite element study of the tank and to confirm by burst test, in accordance with ASME code, the calculated working pressure.

The strain gauges were fitted in critical locations on the inside and outside of the shell. The shakedown of the vessel was successfully carried out also demonstrating satisfactory mechanical stress relief. Various tests simulating the tank support conditions were carried out to obtain stress levels for correlation with the results of a finite element study. The pressurisation of the vessel for the burst test extended over several hours with the burst achieved at 2463.9 kPa by failure of a junction of the internal bulkhead to the external shell. The strain levels recorded during this test indicated that very large plastic deformations (Fig. 23) occurred in various locations without a failure. When plotted, the strain gauge data clearly shows the stress re-distribution and in some locations rapid change in the strain levels.

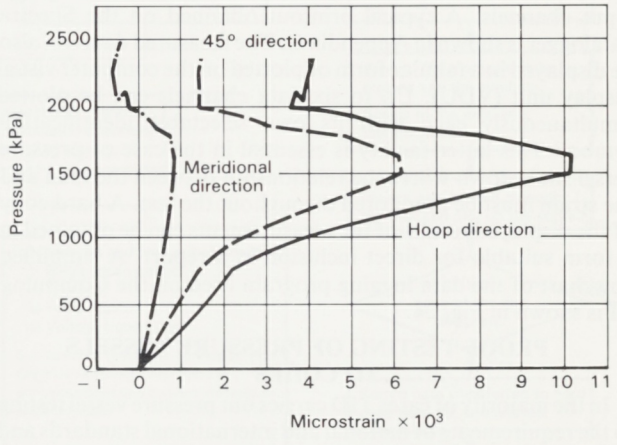


Fig. 23 Burst test-strain redistribution

Metallurgical investigation of the fracture revealed no defects in the material or weld metal and it was concluded that the geometry of the construction detail of the vessel may have generated, in this particular location, a high level of stress concentration in the bulkhead plate and ultimately caused the failure. A small indentation of the plate near the origin of the fracture may have also contributed to the failure in this particular location. Subsequent inquiry revealed that the indentation was the result of careless removal of a temporary lining up attachment.

The test established the burst pressure but also highlighted that in general. any constraint that limits the vessel's elastic-plastic deformations may initially increase the burst pressure. If not carefully designed these constraints will also produce a strain concentration that will cause local failure before the maximum stress intensity in the wall of the vessel, away from the constraint, becomes critical. It appears that the failure of this vessel was not controlled by plastic instability in the vessel's shell, but rather by failure, after considerable yielding, due to local stresses at the strain concentration.

8. DATA ACQUISITION STORAGE AND ANALYSIS METHODS

In general, the data logging computer programs developed in TID for either Compulog III or Spectra data loggers allow maximum flexibility in the choice of logging and data processing routines. The programs are divided into three major sections; data acquisition and storage, analysis and data display.

The analogue to digital conversion of the input signals of various transducers is controlled by software options. The input channels can be scanned in pre-arranged groups, or individually, with a choice of scanning speeds. The programs not only allow flexibility in the choice of scanning speeds but also facilitate continuous or timed modes of scanning applicable to long term logging operations.

The mode of signal conditioning by the input amplifiers can be redefined at any stage during the test. The new amplifier settings can be selected for a group of input channels or individual channels. The binary pattern of the measured signal is then stored on a mass storage media such as floppy disc or magnetic tape. The pattern is converted to voltages and subsequently to engineering quantities, i.e. strain, pressure and deflection, using appropriate constants defined by calibration procedures.

In the case of strain readings the measured levels are utilised for the evaluation of principal and Cartesian stresses, the directions of principal planes and membrane and bending stresses. The calculations are carried out for each strain gauged location using the relationships given in section 6.1.

The results of the computations are channelled to the line printer, tabulated and identified with the respective strain gauge input channels. A typical printout obtained on the Spectra datalogger is shown in Appendix G. The measured data can also be displayed in a tabular form or plotted on the computer visual display unit (VDU). Up to six data channels can be plotted simultaneously each with its own selectable identification symbol. This latter facility is essential in the case of pressure vessel shakedown where the relationship between the load and the strain must be monitored throughout the test. A hard copy of the displayed results of the measurements can be obtained in a form suitable for direct inclusion in a report. A simplified flowchart of the data logging program used on the Compulog III is shown in Fig. 24.

9. PROOF TESTING OF PRESSURE VESSELS TO CODES

In the majority of cases TID carries out pressure vessel testing to the requirements of national and international standards and specifications. The most frequently encountered standards are BS 5500 and ASME VIII.

BS 5500—1982 Section 5.8.6 specifies that for all the parts of a pressure vessel for which the strength cannot be satisfactorily calculated the design pressure will have to be determined from the results of an approved hydraulic test. The standard also recommends that either the strain gauge technique or a strain indicating coating technique should be used to monitor the test. If the strain gauge technique is adopted, any indication of localised permanent set may be disregarded provided that there is no evidence of general distortion of the vessel. If a strain indicating coating technique is used, then the onset of the yielding on outside surfaces should be considered to indicate significant yielding of the shell as in a majority of cases of vessels under internal pressure the maximum stress occurs on the internal surface of the shell. The code also specifies as an overriding requirement that the test pressure should not result in a general membrane stress in excess of 90% of the minimum specified yield or proof stress of the material, in any part of the vessel, at any time during the test. Additionally general guidelines for the test procedure and evaluation of the test results are given. The shakedown procedure given in Section 8.2 of this paper substantially follows the code test procedure recommendations.

The ASME Code Section VIII Division 1 also recommends that the hydraulic proof test is to be carried out and monitored using either strain indicating coating techniques or strain gauges. The guidelines given by the code for strain gauge and brittle coating measuring techniques and for the evaluation of the results of the measurements are not dissimilar to those given by BS 5500. In addition, however, it specifies that during the tests for the most highly strained locations the permanent strain should not exceed 0.2% for aluminium-base, nickel-base, carbon low-alloy and high-alloy steels and 0.5% strain under pressure for copper base alloys. The above requirement in light of the authors' experience seems somewhat too stringent, as considerable yielding can take place locally in the stress concentration area; in some cases well in excess of 0.2% for steels, without detrimental effects to the integrity of the vessel. In these areas the subsequent application of pressure would normally result in the arrest of yielding and strain gauges located in these positions would indicate linearity of the load/strain relationship.

10. CONCLUSIONS

The electric resistance strain gauge techniques employed to monitor the stresses in critical areas of the pressure vessels enable the authors to carry out pressure tests with confidence. The shakedown of the vessel and to some extent mechanical stress relief can also be satisfactorily demonstrated. Current techniques for strain monitoring using micro or mini-computer based data loggers facilitate rapid data collection, evaluation and display of the results during the execution of the test.

The results of the measurements form either the basis for further correlation studies or routine approval of the vessel for the intended service.

11. ACKNOWLEDGEMENTS

The authors wish to express their gratitude for the valuable assistance they have received from a number of colleagues in the preparation of this paper. The authors also wish to thank Welwyn Strain Measurement Ltd., Pye Unicam Ltd., Graham & White Instruments Ltd., and Intercole Systems Ltd., for their assistance in compiling the various tables and data on strain gauges, strain gauge cements and data loggers.

12. BIBLIOGRAPHY

1. C. C. Perry and H. R. Lissner: "The Strain Gauge Primer". McGraw-Hill Book Company, Inc., 1955.
2. A. L. Window: "Bonded Resistance Strain Gauges in Stress Analysis". C.M.E. July/August 1983.
3. J. D. Fox, H. Kraus and R. K. Penny: "Shakedown of Pressure Vessels with Ellipsoidal Heads". Proc. Inst. Mech. Eng. Vol. 183 30/72.
4. J. D. Verhoeren: "Fundamentals of Physical Metallurgy". John Wiley & Sons, 1975.
5. BS 5500: 1982 Issue 1, June 1982.
6. ASME Boiler and Pressure Vessel Code, Section VIII Division, 1, 1980 Edition.
7. H. H. Bednar: "Pressure Vessel Design Handbook". Van Nostrand Reinhold Company, 1981.
8. A. Kelly and R. B. Nicholson "Strengthening Methods in Crystals".
9. J. W. Dally and W. F. Riley: "Experimental Stress Analysis". International Student Edition (Second Edition) McGraw-Hill Book Company, Inc.
10. J. Pople: "B.S.S.M. Strain Measurement Reference Book". The British Society of Strain Measurement, 1979.
11. Strain Gauge Technology: edited by A. L. Window and G. S. Holister, London: Applied Science Pub., 1982.
12. F. A. McLlintock and A. S. Argon: "Mechanical Behaviour of Materials". Addison-Wesley Publishing Company, Inc., 1966.

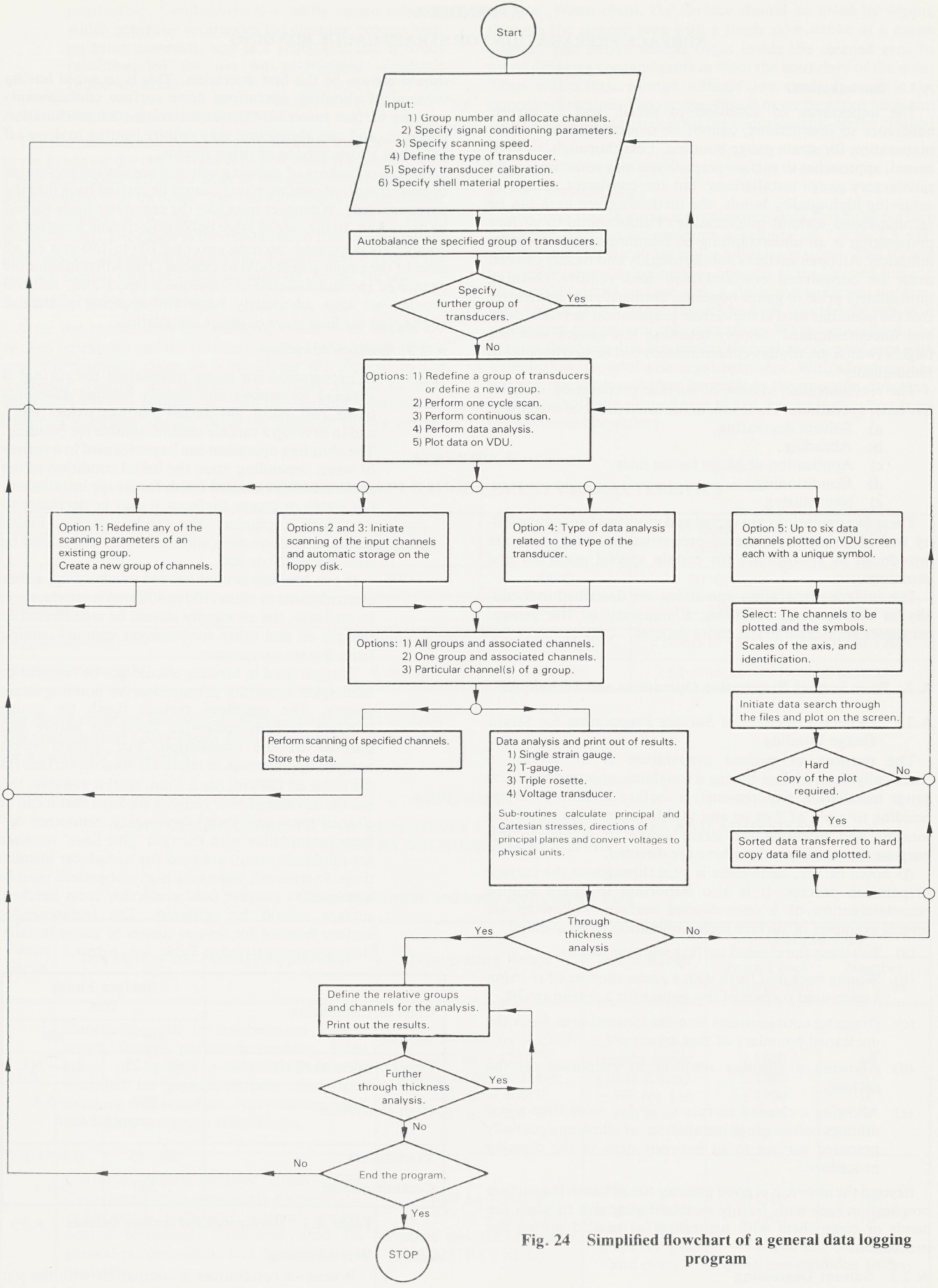


Fig. 24 Simplified flowchart of a general data logging program

APPENDIX A

SURFACE PREPARATION FOR STRAIN GAUGE BONDING

A.1 Introduction

The importance of attention to detail, and of precise adherence to instructions, cannot be overstressed in surface preparation for strain gauge bonding. Less thorough, or even casual, approaches to surface preparation may sometimes yield satisfactory gauge installations; but for consistent success in achieving high-quality bonds, the methods given here can be recommended without qualification. Fundamental to surface preparation is an understanding of cleanliness and of contamination. All open surfaces not thoroughly and freshly cleaned must be considered contaminated and require cleaning immediately prior to gauge bonding. Similarly, it is imperative that the materials used in the surface preparation be fresh, clean and uncontaminated. Simply touching the gauges with the fingers (which are always contaminated) can be detrimental to bond quality.

The recommended system of surface preparation includes five basic operations. These are, in the usual order of execution:

a) Solvent degreasing,
b) Abrading,
c) Application of gauge layout lines,
d) Conditioning,
e) Neutralizing.

These five operations are varied and modified for compatibility with different test material properties and exceptions are introduced as appropriate for certain special materials and situations.

The surface preparation operations are described individually in section A.2, following a summary of the general principles applicable to the entire process.

A.2 Basic Surface Preparation Operations and Techniques

A.2.1 General Principles of Surface Preparation for Strain Gauge Bonding.

The purpose of surface preparation is to develop a chemically clean surface having a roughness appropriate to the gauge installation requirements, a surface alkalinity corresponding to a pH of 7 or so and visible gauge layout lines for locating and orienting the strain gauge. It is toward this purpose that the operations here are directed.

As noted earlier, cleanliness is vital throughout the surface preparation process. It is also important to guard against recontamination of a once-cleaned surface. Following are several examples of surface recontamination to be avoided.

(a) Touching the cleaned surface with the fingers.

(b) Wiping back and forth with a gauze sponge, or re-using a once-used surface of the sponge (or a cotton swab).

(c) Dragging contaminants into the cleaned area from the uncleaned boundary of that area.

(d) Allowing a cleaning solution to evaporate on the surface.

(e) Allowing a cleaned surface to sit for more than a few minutes before gauge installation, or allowing a partially prepared surface to sit between steps in the cleaning procedure.

Beyond the above, it is good practice to approach the surface preparation task with freshly washed hands and to wash the hands or clean them with neutralizer as needed during the procedure.

A.2.2 Solvent Degreasing

Degreasing is performed to remove oils, greases, organic contaminants and soluble chemical residues. Degreasing should always be the first operation. This is to avoid having subsequent abrading operations drive surface contaminants into the surface material. Porous materials such as titanium, cast iron, and cast aluminium may require heating to drive off absorbed hydrocarbons or other liquids.

Spray applicators of cleaning solvents are always preferable because dissolved contaminants cannot be carried back into the parent solvent. Whenever possible, the entire test piece should be degreased. In the case of large bulky objects which cannot be completely degreased, an area covering 100 to 150 mm on all sides of the gauge area should be cleaned. This will minimize the chance of recontamination in subsequent operations, and will provide an area adequately large for applying protective coatings in the final stage of gauge installation.

A.2.3 Surface Abrading

A.2.3.1 In preparation for gauge installation the surface is abraded to remove any loosely bonded adherents (scale, rust, paint, galvanized coatings, oxides, etc.), and to develop a surface texture suitable for bonding. The abrading operation can be performed in a variety of ways, depending upon the initial condition of the surface and the desired finish for gauge installation. For rough or coarse surfaces, it may be necessary to start with a grinder, disc sander, or file. Finish abrading is done with silicon-carbide paper ending with grade 320 or 400.

If grit blasting is used instead of abrading, either clean alumina or silica (100 to 400 grit) is satisfactory. In any case, the air supply should be well filtered to remove oil and other contaminant vapours coming from the air compressor.

The grit used in blasting should not be recycled or used again in surface preparation for bonding strain gauges. The optimum surface finish for gauge bonding depends somewhat upon the nature and purpose of the installation. For general stress analysis applications, a relatively smooth surface (in the order of 100 μin, (or 2.5 μm, rms) is suitable, this has the advantage over rougher surfaces that it can be cleaned more easily and thoroughly. Smoother surfaces, compatible with the thin 'glue lines' required for minimum creep, are used for transducer installations. In contrast, when very high elongations must be measured, a rougher (and preferably cross hatched) surface should be prepared. The recommended surface finished for several classes of gauge installations are summarized in Table A.1, below.

Class of Installation	Surface Finish rms	
	μin	μm
General stress analysis	63—125	1.6—3.2
High elongation	>250 cross hatched	>6.4
Transducers	16—63	0.4—1.6
Ceramic cement	>250	>6.4

Table A.1 Recommended surface finishes

A.2.3.2 Wet Abrading

Whenever conditioner is compatible with the test material the abrading should be done while keeping the surface wet with this solution, if physically

practicable. Conditioner is a midly acidic solution which generally accelerates the cleaning process and, on some materials, acts as a gentle etchant. It is not recommended for use on magnesium, synthetic rubber or wood.

A.2.4 Gauge-Location Layout Lines

The normal method of accurately locating and orienting a strain gauge on the test surface is to first mark the surface with a pair of crossed reference lines at the point where the strain measurement is to be made. The lines are made perpendicular to one another, with one oriented in the direction of strain measurement. The gauge is then installed so that the triangular index marks defining the longitudinal and transverse axes of the grid are aligned with the reference lines on the test surface.

A.2.5 Surface Conditioning

After the layout lines are marked, conditioner should be applied repeatedly and the surface scrubbed with cotton-tipped applicators until a clean tip is no longer discoloured by the scrubbing. During this process the surface should be kept constantly wet with conditioner until the cleaning is completed. Cleaning solutions should never be allowed to dry on the surface. When clean, the surface should be dried by wiping through the cleaned area with a single slow stroke of a gauze sponge. The stroke should begin inside the cleaned area to avoid dragging contaminants in from the boundary of the area. Then, with a fresh sponge, a single slow stroke is made in the opposite direction. The sponge should never be wiped back and forth, since this may redeposit the contaminants on the cleaned surface.

A.2.6 Neutralizing

The final step in surface preparation is to bring the surface condition back to an optimum alkalinity of 7.0 to 7.5 pH, which is suitable for strain gauge adhesive systems. This should be done by applying neutralizer liberally to the cleaned surface and scrubbing the surface with a clean cotton-tipped applicator. The cleaned surface should be kept completely wet with neutralizer throughout this operation. When neutralized, the surface should be dried by wiping through the cleaned area with a single slow stroke of a clean gauze sponge. With a fresh sponge a single stroke should then be made in the opposite direction, beginning with the cleaned area to avoid recontamination from the uncleaned boundary.

APPENDIX B

EXAMPLES OF STRAIN GAUGE CEMENT CHARACTERISTICS

TYPE	Philips 9244/04	M-Bond 200	M-Bond AE15	M-Bond 600
Max. temperature for static measurement	50°C	55°C	90°C	270°C
Elongation		>6%	10—15%	3%
Typical curing time	15 minutes at 20°C	5 minutes at 20°C	2 hours at 65°C	2 hours at 120°C
Storage life at 25°C.	6 months	6 months	12 months	6 months

The above examples are typical but not complete sets of data. The manufacturers data sheets should be studied before using for a particular application.

APPENDIX C

SOME CHARACTERISTICS OF COMMONLY USED STRAIN GAUGES AND ADHESIVES MADE BY MICROMEASUREMENTS

Gauge application and basic performance data

Gauge Series	Description and Primary Application	Temperature Range	Strain Range	Fatigue Life	
				Strain Level in Microstrain	Number of Cycles
EA	Constantan foil in combination with a tough, flexible polyimide backing. Wide range of options available. Primarily intended for general-purpose static and dynamic stress analysis. Not recommended for highest-accuracy transducers.	Normal: −100° to +350°F (−75° to +175°C) Special or Short-Term: −320° to +400°F (−195° to +205°C)	±3% for gauge lengths under $\frac{1}{8}$ in (3.2 mm). ±5% for $\frac{1}{8}$ in and over	±1800 ±1500 ±1200	10^5 10^6 10^8
CEA	Universal general-purpose strain gauge. Constantan grids completely encapsulated in polyimide, with large, integral, copper-coated terminals. Primarily used for general-purpose static and dynamic stress analysis.	−100° to +400°F (−75° to +205°C) Stacked rosettes limited to +125°F (+50°C)	±3% for gauge lengths under $\frac{1}{8}$ in (3.2 mm). ±5% for $\frac{1}{8}$ in and over.	±1500 ±1500	10^5 10^6*
				*Fatigue life improved using low-modulus solder.	

Strain Gauge Series and Adhesive Selection

Type of test or Application	Operating Temperature range	Test duration in Hours	Accuracy required	Cyclic Endurance reqd.		Typical selection	
				Maximum Strain, $\mu\epsilon$	Number of Cycles	Gauge Series	M-Bond Adhesive
General Static or Static-dynamic stress analysis	−50° to +150°F (−45° to +65°C)	$<10^4$	Moderate	± 1 500	$<10^6$	CEA, EA	200 or AE-10
		$>10^4$	Moderate	± 1 500	$<10^6$	CEA, EA	AE-10 or AE-15
		$>10^4$	Very High	± 1 500	$>10^6$	WA, SA	AE-15 or 610
		$>10^4$	High	± 2 000	$>10^6$	WK, SK	AE-15 or 610
	−50° to +400°F (−45° to +205°C)	$<10^3$	Moderate	± 1 500	$<10^6$	WA, SA	600 or 610
		$>10^3$	High	± 2 000	$<10^6$	WK, SK	600 or 610
	−452° to +450°F (−269° to +230°C)	$>10^3$	Moderate	± 2 000	$>10^6$	WK, SK	610
	<600°F (<315°C)	$<10^2$	Moderate	± 1 800	$<10^6$	WK	610
	<700°F (<370°C)	<10	Moderate	± 1 500	$<10^6$	WK	610

APPENDIX D

PRECISION RESISTORS FOR STRAIN GAUGE CIRCUITS

Shunt-Calibration Resistors

	Part number	Resistance in ohms	Tolerance in %	Equivalent microstrain
FOR 120-OHM GAUGE CIRCUIT	W-599880-02	599 880	±0.02	100
	W-119880-02	119 880	±0.02	500
	S-59880-02	59 880	±0.02	1 000
	S-29880-02	29 880	±0.02	2 000
	S-19880-02	19 880	±0.02	3 000
	S-14880-02	14 880	±0.02	4 000
	S-11880-02	11 880	±0.02	5 000
	S-5880-02	5 880	±0.02	10 000
FOR 350-OHM GAUGE CIRCUIT	W-349650-02	349 650	±0.02	500
	W-174650-02	174 650	±0.02	1 000
	S-87150-02	87 150	±0.02	2 000
	S-57983-02	57 983	±0.02	3 000
	S-43400-02	43 400	±0.02	4 000
	S-34650-02	34 650	±0.02	5 000
	S-17150-02	17 150	±0.02	10 000
FOR 1000-OHM GAUGE CIRCUIT	W-999000-02	999 000	±0.02	500
	W-499000-02	499 000	±0.02	1 000
	W-249000-02	249 000	±0.02	2 000
	W-165666-02	165 000	±0.02	3 000
	W-124000-02	124 000	±0.02	4 000
	S-99000-02	99 000	±0.02	5 000
	S-49000-02	49 000	±0.02	10 000

The Equivalent Microstrain column shows the true compression strain simulated by shunting each calibration resistor across an active strain gauge arm of the exact indicated resistance. This is based on a circuit gauge factor setting of 2,000.

Bridge Completion Resistors

Part number	Resistance in ohms	Tolerance in %	Pairs matched to
DSR2/2-120-01	120/120	±0.01	50 ppM
S2-240-01	240/240	±0.01	50 ppM
DSR2/2-250-01	350/350	±0.01	50 ppM
S2-500-01	500/500	±0.01	50 ppM
S2-1000-01	1000/1000	±0.01	50 ppM
S2-2000-01	2000/2000	±0.01	50 ppM
S2-5000-01	5000/5000	±0.01	50 ppM
H2-120-01	120/120	±0.01	20 ppM
H2-350-01	350/350	±0.01	20 ppM
H2-1000-01	1000/1000	±0.01	20 ppM
H2-5000-01	5000/5000	±0.01	20 ppM

50 ppM = 0.005%. 20 ppM = 0.002%.
All resistors are matched at 24°C.

APPENDIX E
BASIC STRAIN RELATIONSHIPS

The strain gauge shown in Figs. E1 and E2 is located α degrees from the x axis. If at first the gauge is strained in the x direction only, and ignoring the Poissonian effect for a moment, the strain in the gauge direction can be defined as:

$$\epsilon = \frac{dl}{l}$$

where $dl = dx \cos\alpha$

and $l = \frac{L_x}{\cos\alpha}$

then substituting for dl and l

$$\epsilon_\alpha = \frac{dx \cos^2\alpha}{x}$$

but $\epsilon_\alpha = \frac{dx}{x}$

and so finally $\epsilon_\alpha = \epsilon_x \cos^2\alpha$

The expression for the strain in direction α due to application of a strain in the y direction only could be arrived in a similar manner and is:

$$\epsilon_\alpha = \epsilon_y \sin^2\alpha$$

If a shearing strain γ_{xy} is applied, the strain recorded by the gauge in α direction can be arrived at as follows:

$$dl = dx \cos\alpha$$

and from geometry of Fig. E2

$$dx = L_y \tan \gamma_{xy}$$

for small γ_{xy} angles we can also write:

$$dx = L_y \gamma_{xy}$$

then $dl = L_y \gamma_{xy} \cos\alpha$

and $\epsilon = \frac{dl}{l} = \frac{L_y \cos\alpha \sin\alpha}{L_y}$

so $\epsilon_\alpha = \gamma_{xy} \sin\alpha \cos\alpha$

If the strains act simultaneously the gauge will record:

$$\epsilon_\alpha = \epsilon_x \cos^2\alpha + \epsilon_y \sin^2 + \gamma_{xy} \sin\alpha \cos\alpha$$

or $$\epsilon_\alpha = \frac{\epsilon_x + \epsilon_y}{2} + \frac{\epsilon_x - \epsilon_y}{2}\cos 2\alpha + \frac{\gamma_{xy}}{2}\sin 2\alpha$$

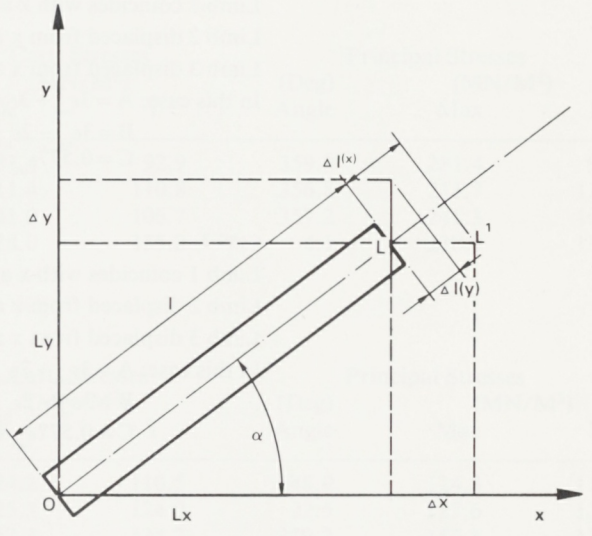


Fig. E1 Strain gauge deformation due to strain in X and Y directions

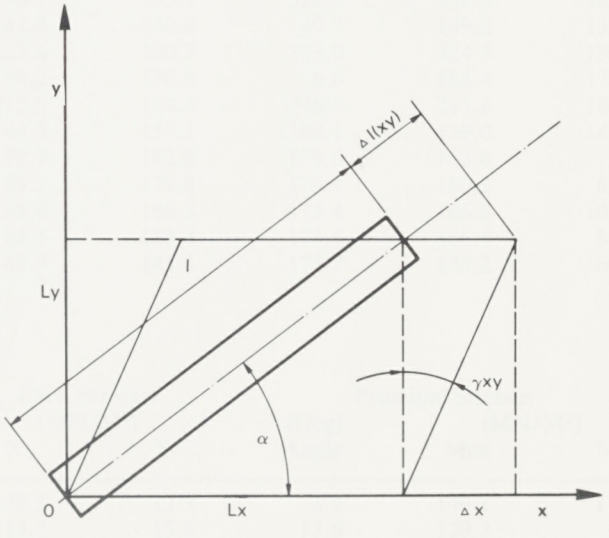


Fig. E2 Strain gauge deformation due to shear strain

APPENDIX F

CALCULATION OF UNKNOWN STRAINS FROM STRAINS IN GENERAL DIRECTIONS

The general expression for calculating constants A, B and C given in Section 6.1 are evaluated for three types of triple gauge rosettes.

CASE 1

Limb 1 coincides with x axis ($\alpha_o = 0°$).
Limb 2 displaced from x axis by 45°.
Limb 3 displaced from x axis by 90° and coincides with y axis.
In this case: $A = \frac{1}{2}(\epsilon_{\alpha o} + \epsilon_{\alpha 2})$

$$B = \tfrac{1}{2}(\epsilon_{\alpha o} - \epsilon_{\alpha 2})$$

$$C = \tfrac{1}{2}(2\epsilon_{\alpha 1} - \epsilon_{\alpha 0} - \epsilon_{\alpha 2})$$

where $\epsilon_{\alpha o}$, $\epsilon_{\alpha 1}$ and $\epsilon_{\alpha 2}$ are measured strain levels in limbs 1, 2 and 3 respectively.

CASE 2

Limb 1 coincides with x axis ($\alpha_o = 0°$)
Limb 2 displaced from x axis by 60°
Limb 3 displaced from x axis by 120°
In this case: $A = 3\epsilon_{\alpha o} + 3\epsilon_{\alpha 1} - 4\epsilon_{\alpha 2}$

$$B = 3\epsilon_{\alpha o} - 2\epsilon_{\alpha 1} + 5\epsilon_{\alpha 2}$$

$$C = 0.577\epsilon_{\alpha o} - 1.1517\epsilon_{\alpha 1} - 1.7321\epsilon_{\alpha 2}$$

CASE 3

Limb 1 coincides with x axis ($\alpha_o = 0°$)
Limb 2 displaced from x axis by 120°
Limb 3 displaced from x axis by 240°
In this case: $A = 3\epsilon_{\alpha o} + 2\epsilon_{\alpha 1} - 4\epsilon_{\alpha 2}$

$$B = 3\epsilon_{\alpha o} - 2\epsilon_{\alpha 1} + 5\epsilon_{\alpha 2}$$

$$C = 0.577\epsilon_{\alpha o} + 1.1547\epsilon_{\alpha 1} - 1.7321\epsilon_{\alpha 2}$$

APPENDIX G
SPECTRA DATA LOGGER OUTPUT EXAMPLE

ROSETTE ANALYSIS

Date 24/2/83 Time 11:49:31 Scan No. 19 Load = 440

GROUP No. 1

	Limb Strains (Microstrain)			Cart. Stresses (MN/M²)		Principal Stresses (Deg)	(MN/M²)	
Chans	A	B	C	X	Y	Angle	Max	Min
0, 1, 2	−178.7	2.9	400.2	−13.3	78.5	190.2	81.6	−16.4
3, 4, 5	−175.9	−21.9	382.2	−13.9	74.6	192.1	78.8	−18.1
6, 7, 8	−371.7	−152.1	92.2	−77.9	−4.4	181.5	−4.3	−77.9
9, 10, 11	−359.4	−97.9	106.5	−74.1	−.3	176.5	−.0	−74.4

GROUP No. 2

	Limb Strains (Microstrain)			Cart. Stresses (MN/M²)		Principal Stresses (Deg)	(MN/M²)	
Chans	A	B	C	X	Y	Angle	Max	Min
32, 33, 34	1230.5	621.2	41.3	281.4	92.9	359.3	281.4	92.9
35, 36, 37	864.9	512.1	230.0	211.4	110.8	356.8	211.7	110.5
38, 39, 40	1014.3	549.4	167.1	241.0	106.7	357.2	241.3	106.4
41, 42, 43	958.3	681.1	309.6	238.0	135.2	4.1	238.5	134.6

GROUP No. 3

	Limb Strains (Microstrain)			Cart. Stresses (MN/M²)		Principal Stresses (Deg)	(MN/M²)	
Chans	A	B	C	X	Y	Angle	Max	Min
64, 65, 66	442.1	381.2	355.6	124.2	110.5	348.9	124.8	110.0
67, 68, 69	427.8	427.8	419,3	125.3	124.0	22.5	125.6	123.7
70, 71, 72	567.6	494.4	425.0	157.3	134.7	359.2	157.3	134.7
73, 74, 75	753.9	668.3	638.9	214.1	195.8	347.0	215.1	194.8
76, 77, 78	704.5	696.9	568.5	198.1	176.5	20.8	201.7	172.9
79, 80, 81	736.8	590.4	640.8	210.3	195.1	328.0	220.0	185.4
82, 83, 84	488.7	528.6	474.4	142.8	140.6	40.7	149.2	134.2
85, 86, 87	822.4	652.1	551.4	223.6	180.7	353.0	224.3	180.0
91, 92, 93	645.5	612.3	560.9	184.2	170.8	6.0	184.4	170.7
94, 95, 96	760.6	630.3	586.6	212.0	184.4	346.8	213.6	182.8
97, 98, 99	471.5	545.7	552.4	144.3	157.1	160.1	159.0	142.3
100, 101, 102	116.0	409.8	683.6	72.7	162.6	179.0	162.6	72.6
103, 104, 105	154.0	491.5	748.2	85.7	179.8	176.1	180,3	85.2
106, 107, 108	242.4	537.1	750.1	105.8	186.3	175.4	186.8	105.3
109, 110, 111	169.2	483.0	679.8	84.5	165.4	173.5	166.4	83.4
112, 113, 114	114.1	380.3	606.5	67.0	145.1	177.7	145.2	66.9

GROUP No. 4

	Limb Strains (Microstrain)			Cart. Stresses (MN/M²)		Principal Stresses (Deg)	(MN/M²)	
Chans	A	B	C	X	Y	Angle	Max	Min
16, 17, 18	659.5	309.6	−143.5	139.5	12.3	3.7	140.1	11.8
19, 20, 21	531.7	380.4	−90.4	114.2	15.6	13.6	120.3	9.5
22, 23, 24	676.2	385.3	61.9	157.3	59.9	1.5	157.3	59.9
25, 26, 27	708.6	428.5	99.3	167.2	70.6	2.3	167.3	70.4

GROUP No. 4

Chans	Limb Strains (Microstrain) A	B	C	Cart. Stresses (MN/M²) X	Y	Principal Stresses (Deg) Angle	(MN/M²) Max	Min
48, 39, 50	−481.1	−188.2	298.5	−88.6	34.9	187.0	36.8	−90.5
51, 52, 53	−464.9	−75.1	377.4	−79.6	53.9	182.1	54.1	−79.8
54, 55, 56,	−487.7	−211.1	33.3	−108.1	−25.6	178.2	25.5	−108.2
57, 58, 59	−811.9	−469.6	−173.0	−195.5	−94.3	178.0	−94.2	−195.7

GROUP No. 6

Chans	Limb Strains (Microstrain) A	B	C	Cart. Stresses (MN/M²) X	Y	Principal Stresses (Deg) Angle	(MN/M²) Max	Min
120, 121, 122	869.9	599.9	255.7	214.3	117.0	3.4	214.6	116.6
123, 124,125	886.1	485.8	200.6	214.2	105.6	355.2	215.0	104.8
126, 127, 128	637.0	487.7	271.0	162.6	104.6	5.2	163.1	104.1
129, 130, 131	30.4	326.1	625.6	49.4	143.7	180.2	143.7	49.4
132, 136, 137	−57.0	643.6	315.6	8.5	67.6	145.0	124.7	−48.6
135, 136, 137	−132.1	198.7	693.1	17.2	147.9	185.6	149.2	15.9
138, 139, 140	394.5	309.0	605.6	130.4	163.9	210.5	181.8	112.6
141, 142, 143	6.7	307.1	543.8	38.4	123.6	176.6	123.9	38.1
144, 145, 146	88.4	318.5	488.7	53.2	116.6	175.7	117.0	52.8
147, 148, 149	220.6	360.3	534.3	86.2	135.9	183.1	136.1	86.1
150, 151, 152	−238.6	328.9	591.3	−13.9	117.7	169.9	122.0	−18.2
153, 154, 155	386.9	595.1	561.9	125.7	153.5	153.0	163.2	116.0
156, 157, 158	135.0	555.2	734.9	80.5	175.5	169.1	179.2	76.8
159, 160, 161	70.4	315.6	596.1	56.4	139.7	181.9	139.8	56.3
162, 163, 164	40.9	243.4	611.3	50.8	141.2	188.1	143.0	48.9
165, 166, 167	113.1	459.2	681.7	71.9	162.0	173.9	163.0	70.9
168, 169 , 170	219.6	410.7	603.7	90.7	151.6	180.1	151.6	90.7

THROUGH THICKNESS ANALYSIS

Date 24/2/83 Time 11:49:31 Scan No. 19 Load = 440

GROUPS No. 1, 4

Chans	Limb Strains (Microstrain) A	B	C	Membrane Stress (MN/M²) X	Y	Bending Stress (MN/M²) X	Y
0, 1, 2	−178.7	2.9	400.2	63.1	45.4	−76.4	33.1
16, 17, 18	659.5	309.6	−143.5				
3, 4, 5	−175.9	−21.9	382.2	50.2	45.1	−64.0	29.5
19, 20, 21	531.7	380.4	−90.4				
6, 7, 8	−371.7	−152.1	92.2	39.7	27.8	−117.6	−32.2
22, 23, 24	676.2	385.3	61.9				
9, 10, 11	−359.4	−97.9	106.5	46.5	35.1	−120.6	−35.4
25, 26, 27	708.6	428.5	99.3				

GROUPS No. 2, 5

Chans	Limb Strains (Microstrain) A	B	C	Membrane Stress (MN/M²) X	Y	Bending Stress (MN/M²) X	Y
32, 33, 34	1230.5	621.2	41.3	96.4	63.9	185.0	29.0
48, 49, 50	−481.1	−298.5	−188.2				
35, 36, 37	864.9	512.1	230.0	65.9	82.3	145.5	28.5
51, 52, 53	−464.9	−75.1	377.4				
38, 39, 40	1014.3	549.4	167.1	66.4	40.6	174.6	66.1
54, 55, 56	−487.7	−211.1	33.3				
41, 42, 43	958.3	681.1	309.6	21.2	20.4	216.7	114.7
57, 58, 59	−811.9	−469.6	−173.0				

GROUPS No. 3, 6

Chans	Limb Strains (Microstrain) A	B	C	Membrane Stress (MN/M²) X	Y	Bending Stress (MN/M²) X	Y
64, 65, 66	442.1	381.2	355.6	169.3	113.7	−45.0	−3.2
120, 121, 122	869.9	599.9	255.7				
67, 68, 69	427.8	427.8	419.8	169.8	114.8	−44.4	9.2
123, 124, 125	886.1	485.8	200.6				
70, 71, 72	567.6	494.4	425.0	160.0	119.7	−2.6	15.1
126, 127, 128	637.0	487.7	271.0				
73, 74, 75	753.9	668.3	638.9	131.7	169.8	82.3	26.1
129, 130, 131	30.4	326.1	625.6				
76, 77, 78	704.5	696.9	568.5	103.3	122.1	94.8	54.5
132, 133, 134	−57.0	643.6	315.6				
79, 80, 81	736.8	590.4	640.8	113.7	171.5	96.6	23.6
135, 136, 137	−132.1	198.7	693.1				
82, 83, 84	488.7	528.6	474.4	136.6	152.2	6.2	−11.7
138, 139, 140	394.5	309.0	605.6				
85, 86, 87	822.4	653.1	551.4	131.0	152.1	92.6	28.6
141, 142, 143	6.7	307.1	543.8				
88, 89, 90	789.1	615.1	485.8	132.4	140.1	79.2	23.5
144, 145, 146	88.4	318.5	488.7				
91, 92, 93	645.5	612.3	560.9	135.2	153.4	49.0	17.4
147, 148, 149	220.6	360.3	534.3				
94, 95, 96	760.6	630.3	586.6	99.1	151.0	112.9	33.4
150, 151, 152	−238.6	328.9	591.3				
97, 98, 99	471.5	545.7	552.4	135.0	155.3	9.3	1.8
153, 154, 155	386.9	595.1	561.9				
100, 101, 102	116.0	409.8	683.6	76.6	169.1	−3.9	−6.5
156, 157, 158	135.0	555.2	734.9				
103, 104, 105	154.0	491.5	748.2	71.0	159.8	14.6	20.1
159, 160, 161	70.4	315.6	596.1				
106, 107, 108	242.4	537.1	750.1	78.3	163.7	27.5	22.6
162, 163, 164	40.9	243.4	611.3				
109, 110, 111	169.2	483.0	679.8	78.2	163.7	6.3	1.7
165, 166, 167	113.1	459.2	681.7				
112, 113, 114	114.1	380.3	606.5	78.9	148.3	−11.8	−3.3
168, 169, 170	219.6	410.7	603.7				

LLOYD'S REGISTER TECHNICAL ASSOCIATION

MINUTES OF THE 1984 ANNUAL GENERAL MEETING

The Annual General Meeting of the Technical Association was held in the Committee Luncheon Room on Wednesday, 23rd May, at 1500 hours. Twenty one members attended.

The President of the Association, Mr W. H. Marsden, occupied the chair:

AGENDA

1. Apologies for absence.
2. Approve and sign minutes of the last AGM.
3. Matters arising from the last AGM.
4. President's Review.
5. Hon. Secretary's Report.
6. Hon. Secretary for Corresponding Members' Report.
7. Hon. Treasurer's Report.
8. Proposed Syllabus for 1984/85 Session.
9. Election of Committee for the 1984/85 Session.
10. Newly elected Committee to assume office.
11. Any other business.

Each item on the Agenda was dealt with as follows:

ITEM 1

Apologies for absence had been received from Messrs. Phillips and Wordsworth.

ITEM 2

The Minutes of the last AGM, held on the 25th May, 1983, were examined by the members present. The minutes were unanimously approved without amendment and signed by the Chairman.

ITEM 3

The Chairman asked the Hon. Secretary if there were any matters arising from the minutes.

The Hon. Secretary replied that there were no matters arising.

ITEM 4

In his review of the past year the President Mr W. H. Marsden said:

"I make no apology for drawing your attention again this year to the hours that are spent by the Hon. Secretaries in providing an active Association. This year, due to transfers and retirements, we had to change quite a number of Secretariat positions during the normal term of appointments. Your Committee made the necessary confirmation of the appointments to enable the work of the Association to proceed.

This gives me the opportunity to thank Jerry Goodwin personally for all the help he gave to me and also to thank John Carlton for his assistance in the effective change to the duties of Hon. Secretary which he has performed. Mr Magill and Mr. McCulloch filled the breach as Honorary Assistant Secretary and Honorary Secretary for Corresponding Members respectively and my thanks also to them.

We have had a very effective year, and the number of papers have increased as well as having two guest lecturers, and for this programme we must thank the Vice-President for his chairing of the Sub-Committee on Technical Papers.

The attendance at the meetings has increased and the discussions have been lively and interesting. We are all striving to place these discussions on record. Perhaps in the future you will be seeing some of this effort in the printed form.

In concluding my term of office as President, my theme has been to improve communications. It is hoped that this purpose has enabled, at least, the Corresponding Members to feel that there is an effective response from the Association. The response from the Corresponding Members to the request for written contributions to the papers was slightly improved. However, the experience in many of the Society's services is now more spread than it was in earlier days of the Association.

I am confident that the new President will strive even more effectively to ensure the Technical Association's voice will be heard and noted throughout the worldwide organisation which is Lloyd's Register".

ITEM 5

The President called upon the Hon. Secretary to report on the Association's activities during the Session. Mr Carlton advised the meeting as follows:

"The L.R.T.A. has had a successful and active year in which a total of six technical papers, two guest lectures and one film have been presented".

PAPER 1. At the first meeting in October, 1983, Mr Blackburn of the Materials and Quality Assurance Department presented his paper entitled "Steel Technology in the 1980's—The Japanese Approach". This paper was read to an audience of 48 members.

PAPER 2. Messrs. Adam and Johnston of the Hull Structures Department read their paper on "The Containment of Bulk Liquid Chemicals in Ships" in November to an audience of 66 members.

PAPER 3. The third paper in the trilogy written by the Computer Department, was presented in December by Mr C. J. J. Beart. His paper entitled "The Reliability of Engineering Computations" was read to a meeting of 34 members.

PAPER 4. Mr A. S. White of the Hull Structures Department presented a paper on the "Structural Design Features of Conversions and Jumboisings" in Febraury to an audience of 43. A request was received for a subsequent reading of this paper by the Newcastle and Middlesbrough Surveyors and this request was complied with on the 12th April, 1984. Thirty two members attended this second reading at the County Hotel in Newcastle.

PAPER 5. A specialist paper entitled "Fuel Chemistry and its Implications on Diesel Engine Operation" was read by Mr C. N. Pontikos of the Advanced Engineering Services Department in March. At the meeting 17 members were present.

PAPER 6. The final paper in the Session was presented by Mr F. Kunz of the Technical Investigation Department, and was entitled "Service Experience with Reduction Gearing". Forty-six members attended this meeting. This paper in a slightly modified form was also presented by the Author to the North East Coast Institution of Engineers and Shipbuilders upon the occasion of their Centenary celebrations in May, 1984.

"In addition to these papers a request was also received from the Newcastle and Middlesbrough Surveyors for a reading of the 1982/83 Session paper entitled 'Fire Protection, Detection and Extinction in Offshore Installations' by Messrs Coggon and Magill of the International Conventions Department. The paper was duly read to an audience comprising forty members at the County Hotel in Newcastle on the 23rd February, 1984.

The L.R.T.A. medal for the 1982/83 Session was presented to Mr R. Porter for his paper entitled 'Non-Destructive Testing in the Society', at the first meeting of the current Session.

The two guest lectures were given in November, 1983 and January, 1984. In keeping with the traditional arrangements for these lectures no printed paper has been published of these two meetings. The first lecture was given by Messrs. J. Hannah and S. C. Drake of the Ministry of Defence, and was entitled 'The Falklands and the Response to Change'. Seventy-five people attended this lecture which was concerned largely with the conversion of merchant vessels at short notice in response to the recent emergency in the South Atlantic. The second guest lecture also continued the Falkland's theme and was given by Mr L. J. C. O'Neil, a retired Salvage Officer. His lecture, which was attended by 47 members, was entitled 'The Return of the "Great Britain" ' a project with which he was closely involved throughout the salvage of Brunel's historic vessel.

A film entitled 'Design and Manufacture of Marine Propellers' was shown during the luncheon period on two consecutive days during December. A total of 70 people attended these film shows.

In keeping with the President's theme of improving communications within the Association, terms of reference for both the Committee and Sub-Committee on Technical papers have been produced. These documents are in effect statements of the duties of these two committees and it is hoped that they will provide a basis for continuity from one session to another when changes of offices are incurred.

This year has also seen an increased usage of the main frame computer for keeping records of both the progress of papers for the current and future sessions and also of general committee information such as committee lists and meeting arrangements. The usage in relation to the progress of the papers has been the most beneficial since the summaries kept on the computer relieve the necessity of continually sifting through the large volume of correspondence associated with each paper.

Now that the Printing House has passed through the introduction phase of their production procedures, a good working relationship has developed between the Printing House and the L.R.T.A. Secretariat. The establishment of this relationship and the helpful attitude of the Printing House staff has considerably eased the work load of the Secretariat.

The format of the Discussion papers has been changed slightly during this Session. In the past it has been traditional to place the contributors in order of seniority irrespective of whether the contribution was made at the time of the meeting or subsequently, in writing. This arrangement which takes the contributions out of chronological sequence, clearly can introduce editorial difficulties. To overcome these problems the discussion has been split into the two components of 'Discussion' and 'Written Contributions'. The former category is now published in order of presentation at the meeting whilst the latter in approximate order of seniority of the contributor. Progress in publishing the discussion papers has been maintained throughout the year, however, it is hoped to streamline this process further during the forthcoming Session.

During the year the Secretariat has been completely changed due to circumstances which were unforeseen at the last AGM. Mr Goodwin retired from the post of Hon. Secretary due to being transferred, albeit temporarily, to Liverpool, and Mr Dawson retired from the post of Assistant Secretary for Corresponding Members of Committee due to his unfortunate retirement from the Society for reasons of ill health. Finally, I would like to record my own thanks to these gentlemen and also the two new members of the Secretariat, Messrs. Magill and McCulloch for their work during the Session''.

ITEM 6

The President then called upon Mr McCulloch, the Assistant Secretary for Corresponding Members to give his report. The meeting was advised that:

''During the Session three Corresponding Members relinquished their responsibilities:

Mr Molenaar, Rotterdam, retired and has nominated Mr Schreuder to replace him.

Mr Nilsson, Gothenburg, retired and has nominated Mr Malmberg.

Mr Hills has been repatriated from Gdansk and has nominated Mr Barrett to succeed him.

Our Corresponding Members continue to play an active role and, in many Outports, informal discussions on technical papers are arranged. Many requests for additional copies of papers have been dealt with during the year.

The Awards Scheme has prompted many members of the Association to read all of the papers, and not just those in which they may have a personal need to study, so that they may assist their Corresponding Member in completing the Adjudication Form. In that connection, I should like to take this opportunity to remind those Corresponding Members who are here this afternoon that their Adjudication Forms should reach me by 30th June. Thank you''.

ITEM 7

The President then asked the Hon. Treasurer to present the statement of the Association's finances during the past year. Mr Wilson reported that:

''The L.R.T.A. accounts remain in a satisfactory state. Although the bank balance is much lower than last year, repayment of the Society's loan for binder purchase has now been completed, and there still remain binders worth £325.

Binders continue to sell well, 230 sold since last audit, and the remainder should last until October/November 1984. By that time the Committee may consider re-ordering. A recent quotation showed a cost of £1.90 each.

In view of possible increased costs, particularly that of entertaining guest speakers who may have travelled far, the Committee may consider seeking a larger annual grant from the Society in the near future.''

The financial statements are reproduced at the end of the AGM Minutes.

ITEM 8

The President asked Mr Rennie the Association's Vice-President and Chairman of the Sub-Committee on Technical papers to present the proposed syllabus for the 1984/85 Session. Mr Rennie advised the meeting as follows:

''A full programme of papers covering diverse topics in the engineering, ship, industrial services and control engineering fields is proposed by the Sub-Committee for Technical papers.

Two of the papers will update information previously published by the L.R.T.A. namely the fire paper by Gordon and Coggon in 1975 and the anchors and moorings paper by A. K. Buckle in 1971, whilst the remaining papers are on topics not previously addressed to the L.R.T.A.''

The proposed programme is as follows:

PAPER 1 3rd October, 1984.
''Pressure Vessel Testing''
by V. M. Kozousek and J. M. Jennings. (HQ/RATAS).

PAPER 2 7th November, 1984.
''Resin Chocks''
by W. Smith. (HQ/RATAS).

PAPER 3 5th December, 1984.
"Fire Safety Aspects of the 1981 Amendments to SOLAS 74"
by D. J. Holland and C. M. Magill. (HQ/ICD).

PAPER 4 6th February, 1985.
"Anchors and Moorings"
by E. W. Larkin and R. C. MacDonald. (HQ/HULL STRUCT./OSG).

PAPER 5 6th March, 1985.
"Industrial Services in Sweden"
by A. Pullar. (GOTHENBURG).

PAPER 6 3rd April, 1985.
"Microprocessors in Ships"
by A. W. Finney (HQ/CONTROL ENG).

RESERVE PAPER
"The Assessment and Certifications of Container Securing Systems on Board Ship"
by J. A. Morris and A. J. Williams. (HQ/HULL STRUCT.).

"In addition to these papers a Guest lecture will be given in January, 1985, by Prof. R. V. Thompson of the University of Newcastle upon Tyne on the subject 'Future Aspects of Marine Technology'.

Offers of papers for the Session 1985/86 have also been received by the Sub-Committee thus the future prospects are looking very good.

The Sub-Committee moves the adoption of the proposed syllabus for the 1985/86 Session."

There were no comments from the members present and the proposed syllabus for the 1984/85 Session was duly ratified.

ITEM 9

The President requested the Hon. Secretary to advise the AGM on the election of Officers to the Committee.

Mr Carlton read out the list of names nominated for the Officers, Members of Committee and Corresponding Members of Committee. In each case there was only one nomination for each office and the nominees were duly elected. The names of those elected are recorded below:

President	:	Mr D. Rennie.
Vice-President	:	Mr L. Beckwith.
Hon. Secretary	:	Mr J. S. Carlton.
Hon. Asst. Secretary	:	Mr C. M. Magill.
Hon. Asst. Secretary for Corresponding Members	:	Mr W. N. G. McCulloch.
Hon. Treasurer	:	Mr T. Lindsay.

COMMITTEE MEMBERS:

Classification Reports (Hull)	Mr J. Lunt
Classification Reports (Machinery)	Mr D. van Dorp
Electrical Engineering	Mr A. W. Finney
Hull Structures	Mr H. A. Ivers
Industrial Services	Mr J. S. Phillips
International Conventions	Mr F. R. Hales
Marine Specification Services	Mr R. M. Hobson
MDAPAD	Mr R. Jeffrey
Offshore Services	Mr D. Harris
Refrigeration	Mr A. A. Wilson
Research Laboratory	Dr F. A. Khayatt
TID/AES	Mr R. V. Pomeroy

CORRESPONDING MEMBERS OF THE COMMITTEE:

AUSTRALASIA	Mr R. B. Last	SYDNEY
BELGIUM AND FRANCE	IR. W. J. G. de Backer	ANTWERP
CANADA	Mr C. A. C. MacGregor	MONTREAL
CENTRAL AMERICA AND THE CARIBBEAN	Mr J. Frize	MEXICO CITY
CENTRAL EUROPE	Mr C. M. Bergmann	HAMBURG
	Ing. G. K. P. Hallap	DUSSELDORF
CENTRAL ORIENT	Mr J. N. Mckay	BUSAN
EASTERN MEDITERRANEAN	Mr J. J. Stansfield	PIRÆUS
IBERIAN PENINSULAR	Mr H. Garcia	MADRID
INDIA AND PAKISTAN	Mr S. V. Ramchandani	BOMBAY
ITALY AND MALTA	Dott. Ing. E. V. Villa	GENOA
JAPAN	Mr K. Miyoshi	OSAKA
	Mr R. Hashiguchi	SHIMONOSEKI
	Mr K. Seki	YOKOHAMA
MIDDLE EAST AREA	Mr S. M. Miskry	BAHRAIN
NETHERLANDS	Ing. A. Schreuder	ROTTERDAM
NORDIC COUNTRIES	Mr J. G. Lassen	COPENHAGEN
	Mr R. S. Malmberg	GOTHENBURG
NORTH AFRICA	Mr S. M. A. Ahmed	ALEXANDRIA
POLAND	Mr A. Barrett	GDANSK
SOUTH AMERICA	Mr R. De. F. Gomes	RIO DE JANEIRO
SOUTHERN AFRICA	Mr C. A. Timms	DURBAN
SOUTHERN ORIENT	Mr B. H. Wong	SINGAPORE
UNITED KINGDOM:		
EAST MIDLANDS	Mr H. Milne	HULL
NORTH ENGLAND	Mr E. Whitehouse	NEWCASTLE
NORTH SCOTLAND	Mr W. F. Rogerson	ABERDEEN
SOUTH EAST	Mr K. J. Fryer	LONDON
SOUTH SCOTLAND	Mr A. R. Morton	GLASGOW
SOUTH WEST AND SOUTH WALES	Mr D. G. Taylor	SOUTHAMPTON
WEST MIDLANDS AND EIRE	Mr J. B. Dunbar	LIVERPOOL
UNITED STATES OF AMERICA	Mr W. E. Tuck	NEW YORK

In keeping with the L.R.T.A. tradition, Mr Marsden and Mr Goodwin were invited to join the L.R.T.A. Committee in an ex officio capacity for the forthcoming year.

The Hon. Secretary also advised the meeting that the Honorary Auditors, Messrs. Leighton and Mounch, were willing to act in this capacity for the 1984/85 Session. The meeting then re-elected Messrs. Leighton and Mounch to continue in office for a further year.

ITEM 10

At this point in the meeting the retiring officers stepped down and the new members of committee took up their office.

Mr Rennie, the L.R.T.A's new President, introduced the Session by thanking Mr Marsden for all his hard work and guidance throughout the preceding two years as the Association's President. He also expressed the L.R.T.A.'s thanks to all those other Committee Members who had retired and gave a welcome to those who had taken up office.

ITEM 11

There being no further business the meeting closed at 15.40.

J. S. Carlton
Hon. Secretary.

LLOYD'S REGISTER TECHNICAL ASSOCIATION

Income and Expenditure Account for year ended 31 March, 1984

	£	£
Sale of 216 Binders		401.40
Less cost of binders (re note 1)		421.36
Deficit		(19.96)
Grant from Society		100.00
		80.04
Less:Expenditure		
Gratuities	58.00	
Entertainment	79.00	
Engraving	7.50	
		144.50
Excess of Expenditure over Income		64.46

Note:1 Cost of binders include one for official presentation and twelve which have been lost or damaged (total of thirteen at a cost of £23.92).

Cash Budget for 1984/85 is as follows:-

	£
Balance of cash 1.4.84	206
Less cost of entertaining, gratuities plus margin for contingencies	250
Estimated deficit	44

NOTE:

1. It is assumed that cost of postage will continue to be borne by the Society.
2. The volume of binder sales is unpredictable, therefore, no account of this has been taken in the above figures.
3. There is the very real liklihood that an order for a fresh stock of binders will be required, approximate cost £1,900.

D. Leighton, F.C.C.A.
M. Mounch, F.C.C.A. } Joint Auditors

1st May, 1984.

LLOYD'S REGISTER TECHNICAL ASSOCIATION

Balance sheet as at 31st March, 1984

1983 £		1984 £	1983 £		1984 £
	General Fund				
593.85	Balance B/F	605.92	466.33	Cash at Bank (Current A/C)	206.13
(12.07)	Less excess of expenditure over income...	64.46			
605.92		541.46	42.55	Sundry Debtors	9.65
650.00	Loan from Lloyd's Register	—			
			747.04	Stock of ring binders in hand at cost ...	325.68
1,255.92		541.46	1,255.92		541.46

N.B. Stock has been valued at lower of cost or net realisable value.

Report of the Auditors to the Members

The above Balance Sheet and attached Income and Expenditure Account has been drawn up from the documents and vouchers of the Association and the explanations given by the Officers thereof. We have examined the Income and Expenditure Account and the Balance Sheet and are satisfied that they show a true and fair view of the activities of the Association for the year ended 31st March, 1984.

D. Leighton, F.C.C.A.
M. Mounch, F.C.C.A.
} Joint Auditors

1st May, 1984.

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Lloyd's Register Technical Association

PRESSURE VESSEL TESTING USING STRAIN MEASURING TECHNIQUES

V. M. Kozousek and J. M. Jennings

Paper No. 1. Session 1984-85

Minutes of 1984 Annual General Meeting



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Discussion

on the paper

PRESSURE VESSEL TESTING USING STRAIN MEASURING TECHNIQUES

by

V. M. Kozousek and J. M. Jennings

Paper No. 1. Session 1984–85

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

Any opinions expressed and statements made in this Discussion Paper are those of the individuals.

Hon. Sec. C. M. Magill
71 Fenchurch Street, London, EC3M 4BS

Discussion on the Paper

PRESSURE VESSEL TESTING USING STRAIN MEASURING TECHNIQUES

by

V. M. Kozousek and J. M. Jennings

DISCUSSION

From Mr. C. M. Magill:

The authors are to be congratulated on the presentation of this excellent paper which explains in great detail the procedure of the strain gauging technique used for pressure vessel testing together with the shakedown procedure and its usefulness as a means of stress relief for those special cases where only partial or no stress relief is possible.

This is particularly relevant to the specialised field which I came in contact with, namely diving chambers and submersibles for manned occupation.

In Section 5.4 concerning strain gauge channel identification it is stated that channel identification is difficult in those cases where the gauges are inaccessible due to waterproofing or similar types of protection. In general, submersibles are designed to withstand external pressure and are tested by submerging in water to the appropriate depth. Since only gauges on the inner surface of the shell may be accessible, the attending surveyor at the test is often faced with the problem of many strain gauges on the outer shell that have been waterproofed, or otherwise protected, and are unidentifiable.

Could the authors offer any practical guidance on a suitable method of channel identification in such cases, if possible at all.

From Mr. H. A. Hancock:

The Specialist Services Group of Hull Structures Department has, for the past two years, been using a variant of the Spectra datalogger for the long-term monitoring of temperature and thermal strain in bitumen carriers. The variant, the Spectra Xb, is directly compatible via TU58 cartridge tapes with the Society's DEC computer systems.

At an early stage of the project, hardware problems, particularly relating to printer operation, were experienced which were thought to be associated with mains voltage transients. The introduction of a line voltage conditioner in the supply circuit appears to have resolved the situation.

I would wish to ask the authors if they have experienced any similar such hardware problems, and if so what remedial measures were taken to prevent such difficulties in the future.

From Mr. B. S. Rajan:

I would thank Mr. Jennings and Mr. Kozousek for a very enjoyable paper. However, one aspect of the paper would benefit from some amplification.

Various different strain gauging techniques have been described viz. encapsulated gauges bonded to steel surfaces, foil gauges bonded to steel surfaces, rosettes bonded to steel surfaces, welded strain gauges etc, and various different bonding agents have been postulated. Now, it can be seen in Fig. 22 that strains of almost 10000 μ strain have been recorded. I would ask the authors to give limits to which they feel each strain gauging technique or combination of strain gauging techniques would be accurate in normal field use.

From Mr. A. J. Rigby:

The pressure vessels tested by the Technical Investigation Department are large and impressive steel structures. It is easy to imagine the temperature effect on such a large area of steelwork and the corresponding need for compensating strain gauges.

Please explain how the compensating strain gauges are mounted to take account of differing structure/compensating plate size and thickness. The heat transfer functions of the large plate area of the structure and the small plate area of the compensating gauge plate would be different; how is it arranged that the temperature of both plates are maintained equal?

From Dr. F. A. Khayyat:

With regard to the heat exchanger that was tested to destruction under internal pressure, a metallurgical investigation reported that failure had occurred in the HAZ. It is interesting to know whether any attempt was subsequently made to evaluate the relative fracture toughness of the HAZ as compared to the weld metal.

To expound on a previous point that was made by one of the contributors regarding the true value of the stress at a weld toe of a pressure vessel, and hence the S.C.F., it is suggested that a photoelastic modelling analysis would provide the true S.C.F. at such a location.

AUTHORS' REPLY

To Mr. Magill:

The authors have no knowledge of an electrical method of identifying strain gauge channels once the connections at the gauge end are waterproofed. Obviously a magnetic or electromagnetic induction device could be tried but success would depend on the radiating power achieved, the thickness of the waterproofing coat and the compatibility of the measurement system with the inducing system. The Surveyor in the situation given by Mr. Magill must rely on good cable identification and wiring checks by the contractor and if possible should ask for a foolproof checking technique to be carried out before waterproofing using a shunt resistance to simulate a strain change at each gauge in turn. The calibration of the system would then be witnessed at the same time. If as a result of the pressure test there is a need to confirm a gauge location it can be done afterwards using a resistance shunt and a pair of wired needles to penetrate the cable insulation near the strain gauge and connect the appropriate pair of conductors with the shunt.

An isolated rosette can often be identified by physical pressure adjacent to the gauge but individual limbs will not be separately affected.

To Mr. Hancock:

The Departments two data logging systems have both at times given problems as a result of power supply deficiencies. In one case the computer VDU was displaying data on both the alpha-numeric and graphic screens offset with respect to the centre of the screen. The result was a partial loss of text and plotted data. A clean power supply had been requested but the fault was only cleared by means of a line conditioner. Now two devices are available and one or the other is always used. The first is a line conditioner which ensures a stable regulated mains voltage, isolates the conditioner output to prevent spikes and transients being passed and filters to remove electrical distortion and noise. The second is an uninterruptable power system which in addition to the uninterruptable feature provides a standard power supply with a low harmonic distortion from a battery system.

To Mr. Rajan:

Strain measuring limits are determined by a combination of a number of factors viz. the gauge foil alloy and its geometric shape, the backing material of the grid, the type of adhesive and the bond to the surface being strained. The strain limit is not affected by normal encapsulation or by a rosette configuration.

Typical maximum strain levels quoted are from 3% to 5% (i.e. 30,000 to 50,000 microstrain) for standard foil gauges, 0.5% for weldable gauges and very high temperature gauges and 20% for super annealed alloy foil gauges. In general cements do not impose a limitation on normal gauges and some cyanoacrylate cements can be used for up to 15% strain.

It can be seen that from an engineering point of view there is no limit to the level of strain which can be measured providing a suitable system is chosen. The authors have had good experience of measuring strains up to 20,000 microstrain using standard gauges and techniques.

To Mr. Rigby:

Temperature compensation of a strain gauge installation arises from the need to reduce the effect of the measured apparent strain due to variation in ambient temperature of the test environment. Modern strain gauges are to a degree self compensating and are capable to operate satisfactorily in the range of up to about 30°C. Constantan (A-alloy) strain gauges will display minimum apparent strain over the temperature range from about −45° to 205°C. The apparent strain induced by temperature can within this range be as high as −100 microstrain. The advent of the computer based data loggers, however, allows the apparent strain curve to be programmed and software based compensation then can be utilised for any known temperature.

In cases where a large number of gauges precludes the software approach and where accuracy of measurement to 10 or less microstrain is required the temperature compensation of individual gauges or groups of gauges is preferred.

The object of the temperature compensation of the strain gauges is to remove apparent strain generated by the thermal differences between the various ambient conditions. The temperature compensation is not intended to remove true thermal strain induced in the test specimen. The compensating gauge being of the same manufacture specification and ideally of the same batch number as of the active gauge should be attached to a small unstrained block of parent metal and positioned in close proximity to the strain gauge or group of strain gauges to be compensated. The thermal differences which will arise during the test will thus act on both active as well as passive strain gauges generating same amount of the apparent strain. Due to the wiring configuration of the strain gauges the apparent strain will be effectively cancelled out and only the true strain will be recorded.

The point to bear in mind when the compensating gauges are prepared and installed is that direct sunlight or other heat sources may have a more immediate effect on the compensating gauge than the active gauge due to size of the compensating block. It is therefore good practice to insulate the compensating gauge from the effects of direct heat sources.

To Dr. Khayyat:

The Authors are not aware of any subsequent tests made to attempt to evaluate the relative fracture toughness of the HAZ as compared to weld metal. The question of true stress and the stress concentration intensity is one of interest but in the testing of the pressure vessels to codes is not of immediate importance. The gauges positioned close to the toes of the welds and to the stress concentration fields are intended to monitor the possible yielding and to check the linear behaviour of the vessel during consecutive applications of the load. The actual values of the strain rather than the stresses are used to evaluate the behaviour of the vessel.

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FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

The author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register of Shipping. Any opinions expressed and statements made in this paper and in the subsequent discussions are those of the individuals.

Written contributions to the discussion of this paper are invited from members of the Lloyd's Register Technical Association. To ensure inclusion in the discussion paper, the contributions should be received by the Hon. Secretary in London not later than the 11th January, 1985.

Hon. Sec. J. S. Carlton
71 Fenchurch Street, London, EC3M 4BS

RESIN CHOCKS

by W. SMITH

SYNOPSIS

The use of commercially available epoxy resin systems in the chocking of main engines and other items has been investigated. The results indicate that for all systems submitted to the Society for approval the most important consideration is temperature; the temperature of the resin prior to mixing, the temperature of the mould, the temperature attained during the exothermic curing process, the service temperature and the rate of temperature rise to service conditions. These temperatures are within a range which might be considered ambient, i.e. 0–80°C, and where 10°C can be the difference between success and failure.

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APPENDIX Guide to the Approval of Epoxy Resin Chocks where Alignment is Critical

1. INTRODUCTION

Plastics were available at the turn of the century but were not developed commercially, to any significant degree, until the latter end of the second quarter. Relatively swiftly they became part of our everyday life.

Much of the development took place in the United States of America and this is reflected in the terminology especially when used colloquially, for example epoxide resins are more often than not referred to as epoxies. Since this paper is intended for the end users of resin chocking compounds trade terms have been used throughout. Similarly, since one does not require a detailed knowledge of the internal combustion engine to drive a car, one does not require a plethora of chemical formulae and reactions to produce satisfactory chocks. Finally, it must be appreciated that the paper is only relevant to commercially available chocking resins and any general statements are limited to materials and properties intended for this application.

In the mid-sixties it was suggested that one branch of the plastics family, the epoxy resins, would be ideal to replace chocks under machinery since they could be mixed and poured *in situ* easily and would totally fill the space between the base of the machinery and its foundation. Apart from cleaning loose dirt, grease and scale no special preparation of the surfaces was required. Characteristics such as surface irregularities, fretting and lack of parallelism, which were difficult if not impossible to contend with by the traditional methods of hand fitting steel or cast iron chocks, could be ignored with pourable resin chocks. The saving in time and money would, therefore, be significant.

Initial investigations were conducted by the Society in collaboration with industry and following both laboratory and field tests, requirements for filled epoxy resin chocks for use where alignment is critical were formulated as shown in the Appendix. Where alignment is controlled by the inherent stiffness of the machinery itself, or where the alignment is maintained by a suitable substructure, the foundation chocks do not require to comply with such stringent requirements.

2. ELEMENTS OF EPOXY RESIN CHOCKING SYSTEMS

A resin chocking system comprises a resin, a curing agent, (more commonly referred to as a hardener) and a filler. A colouring agent is generally added for aesthetic or identification purposes, but plays no other part in the system.

Any chocking epoxy should always be referred to as a system since the properties obtained from a mixture of any one of the many combinations of resins, hardeners, and fillers is unique to that combination. Change any one of the three main constituents, or even their proportions, and a material with different characteristics is obtained.

When in the liquid form all epoxies are dermatitic to some degree; only sensitive skin, however, reacts with the milder systems. Care should always be taken, therefore, to avoid skin and eye contact and protective clothing should be worn. Fumes can cause eye and respiratory irritation and enclosed spaces should be well ventilated. When cured and in the solid state the systems are generally harmless.

2.1 Resins

Pure resins are amber coloured, syrupy liquids composed of individual long-chain-molecules with chemical bonds between the atoms forming the molecule. These bonds can be rearranged to form cross-links between the molecules thus forming a lattice which binds the molecules together and changes the resin from a liquid to a solid.

2.2 Hardeners

When pure, they usually range in colour from being colourless to light amber and have a low viscosity. Occasionally they contain a colouriser. The hardener reacts with the resin to form the cross-linked structure between adjacent resin molecules. The resulting chemical reaction is exothermic and produces no volatile by-products.

2.3 Fillers

Fillers are usually added, not only to increase the bulk and lower the cost, but also to modify the properties of the resin-hardener combination; for example, they significantly increase the compressive strength and decrease the temperature of the mixture during the exothermic reaction. The proportion of the filler plays a major part in the determination of the physical properties and, therefore, no additional filler must be added to an approved chocking system. The fillers are normally mixed with the resin when it is supplied by the manufacturer.

Fillers are usually inert compounds, such as quartz or silica in powdered or finely granulated form. If granulated, they can lead to erratic hardness readings when using the Barcol (Barber Colman) hardness tester which operates on a needle penetration method and which may, or may not, encounter a hard subsurface granule.

On occasions where large deep chocks are required, conservation of chocking resin material may be achieved by casting in pieces of scrap steel. Care should be taken in such cases to ensure that the scrap is encased by at least 12.5 mm of resin. These inserts are not to be confused with fillers and should never be referred to as such.

3. RESIN CHOCK CASTING

3.1 Preparation for Casting

Everything must be prepared before mixing since once mixing is started there is only about 30 minutes available before the resin gels. In tropical situations the time might be less.

The area in contact with the chocking material should be degreased and free from such things as dirt, loose paint and scale. Epoxy resins are adhesive. In chocking situations the cleaned surface is sprayed with a release agent and any items which are replaceable, for example fitted bolts or bungs filling the holding down bolt holes, coated to avoid adhesion. Dams are fitted to form the perimeter of the chock: compressed closed-cell foam neoprene or rubber make ideal dam structures. The thickness is normally cut 10 to 20% oversize so that they are compressed when forced into place. Plasticine and similar materials will also prove adequate, however, newly mixed resin has high searching qualities and will leak through minute gaps; it can seep beneath plasticine not firmly in contact with the surface. The dam must be extended outside the chocking area to provide a pouring area. This pouring area must be positioned such that no air can be trapped within the mould thus preventing the resin mixture from filling the mould completely. In the pouring area the dams must be heightened, to provide a head of resin to feed the casting as it contracts or the mould thermally expands.

In a chocking situation it is normal to extend the dam area 15 to 20 mm outwards from the side of the engine for the full length of the chock and to extend its height by the same amount. This will provide sufficient reserve to feed the average chock.

In other situations, sterntubes for example, where the header does not extend the full length of the resin cast, a deeper header will be required; typically 1% of the cast volume.

3.2 Resin Storage

Storage should be to the manufacturer's requirements. Prior to mixing, the materials should be conditioned such that they are thermally stabilised in the region of 25°C. At this temperature filled resin is viscous and equivalent to about 90 SAE.

Resin viscosity increases with decrease in temperature. High viscosity makes mixing more difficult but more importantly, leads to the probability of air entrapment which must be avoided. During curing entrapped air will rise to the upper surface of the casting and form craters which can substantially decrease the available bearing area. The resultant increase in loading of the remaining bearing area may result in excessive creep deflection.

If the resin temperature is too high, by being left in the sun for example, the curing reaction may proceed so swiftly that the resin gels before it can be poured.

3.3 Mixing

During extended storage the filler tends to settle to some extent, especially if the temperture is high. It is prudent, therefore, to pre-mix for a short time before adding the hardener.

The mixing should be in accordance with the manufacturer's instructions and a mixing paddle is often supplied and paddle RPM recommended. The paddle may be specially designed to facilitate scouring of the sides and bottom of the container. The recommended RPM is usually in the region of 250 for about 3 to 5 minutes. The paddle should be moved slowly and deliberately through all the resin, ensuring that material in contact with the bottom and sides of the mixing container is included. If all the hardener is added at once ensure that no hardener is lost. Entrained air and loss of hardener can arise from increasing the paddle RPM, vigorous stirring with the paddle and allowing the paddle blades to emerge.

It is beneficial to allow the mixture to stand for a short period, 5 to 10 minutes if the temperature allows it, to allow any entrained air to surface and escape.

3.4 Pouring

After mixing the material will remain pourable for some time, often referred to as the 'pot life'. This will vary according to temperature but will usually be of the order of 30 minutes. The actual times are recommended by the manufacturer.

Pour slowly and continuously, avoiding excessive free fall of the mixture. This facilitates the escape of any residual entrained air and avoids further entrapment. Continue pouring until the mould is completely filled and the header is adequate, usually about 15 mm above the highest point of the chock when the header extends for the full length. In situations where the area of the header is limited a greater height must be allowed. The volume of header required will vary with the resin system and with the temperature during cure, but about 1% of the cast volume should be adequate.

3.5 Curing

The chemistry associated with the curing process is very complex and fortunately it is largely irrelevant to the end user. Essentially the chemical reaction between the resin and hardener is exothermic and involves the cross-linking of certain available chemical bonds within one resin molecule with corresponding bonds of adjacent molecules by the incorporation of the hardener. The cross-linking takes time and the proportion of available bonds cross-linked is controlled by the temperature of the material. Eventually a temperature is attained when all the bonds are cross-linked and the material is fully cured. If the temperature of the material is limited during curing the material is part cured, the degree of cure being dependent on the temperature. The degree of cure can be increased at any subsequent time by increasing the temperature of the material above the previous highest temperature.

The physical properties of the material are associated with the proportion of the available bonds cross-linked, that is, the degree of cure. This relationship, however, is not straightforward. Primarily, improving the cure only improves the properties of the material at that temperature, it does not significantly improve the properties associated with temperatures below the temperature required to attain a specific degree of cure. For example, if samples are available with as cured temperatures of 30°C and 80°C the results from both samples would be similar if tested at 30°C, but if tested at 80°C the sample cured at 30°C would fail disastrously.

During the curing process no volatile by-products are produced, nor does the filler take any part in the reaction, it is merely dispersed through the resin matrix.

Curing, therefore, is the transformation of the liquid components of a resin system into a solid and the subsequent development of the physical properties, both of which depend on the cross-linking of chemical bonds between adjacent molecules to form a lattice.

Curing commences immediately the hardener is added and proceeds with time. The reaction is exothermic and the temperature within the material rises. Initially, during the first half hour or so, the rise is gradual then it accelerates. If temperature versus time is recorded the resulting curve is the *EXOTHERM,* though it is common to refer to the maximum temperature recorded as the exotherm. The exotherm is a most important parameter of the curing process as it determines the mechanical and some physical properties of the resulting casting. This period is referred to as the *INITIAL CURE* and the associated properties as the *AS CURED* properties.

Subsequently the material may be heated to higher temperatures, a process referred to as *POST CURING* or more correctly post cure heat treatment. Post curing improves the high temperature properties of the casting. The high temperature properties are improved with temperature until they reach a maximum value, the values often quoted in the manufacturer's literature. As previously mentioned these will also be the properties of the material at any temperature below the highest temperature previously experienced by the material for any length of time.

Each resin system has its own unique temperature at which it is fully cured and similarly in any specific situation each system will attain its own unique exotherm. The minimum temperature experienced in the laboratory to attain full cure was 100°C, the maximum may exceed 200°C.

4. RESIN CHOCKING SYSTEMS

Immediately the hardener is added to the filled resin the exotherm begins. With material stored at 20°C to 25°C the temperature will increase to about 30°C during the first half hour, allowing ample time for mixing, deaerating and pouring. Too low storage temperatures, less than 10°C, can lead to difficulties through poor hardener dispersal, air entrapment and poor flow within the mould. Too high temperatures, in excess of 35°C, and the pot life, or alternatively the time to gel, may be too short to allow pouring to be completed.

On pouring, the material assumes the temperature of the mould within minutes, and curing proceeds from that temperature. The subsequent exotherm is significantly affected by the heat sink effect of the mould. If the mould is small or has poor thermal conductivity the exotherm will be determined by the material, for example, if left in the mixing container temperatures in excess of 200°C may be recorded. If the mould is massive with a high thermal conductivity, the mould will conduct the evolved heat away quickly and the exotherm will be significantly affected by the temperature of the mould which will remain relatively constant.

Resin systems have relatively low thermal conductivity and heat evolved at the centre of a casting is conducted slowly to the outside surface of the casting. The quantity of heat evolved will be proportional to the casting thickness and since during curing the rate of heat evolution in resin systems is proportional to the casting temperature, the thickness of the casting will significantly affect its internal temperature and consequently, its exotherm.

Since both resin casting thickness and the temperature of the mould structure will vary significantly for different applications, the exotherm and hence degree of cure of the casting will vary significantly. For example, with thin 12.5 mm chocks cast in a North European winter where structural temperatures will be low, the exotherm will be low, probably of the order of 20°C. A thick 100 mm chock in the same situation may well achieve an exotherm of 60°C or higher. Alternatively, in the tropics with structural temperatures up to 50°C a thin chock could achieve an exotherm of 80°C while a thick chock could exceed 200°C.

In practice there is very little that can be done to raise the exotherm. The casting thickness required and mould size existing cannot be easily altered and it would be difficult, if not impossible, to substantially raise the temperature of the structure due to its high thermal conductivity. In this respect care must be taken when tempertures are below the manufacturer's recommended minimum casting temperature and hot air heaters are employed to increase the ambient temperature. The minimum temperature applies to the structure, the ambient air temperature is only relevant if it heats the structure to the same temperature.

Where structure temperatures are high, exotherm may be controlled to some extent by pouring the casting in layers, allowing each layer to return to ambient before pouring subsequent layers. The thin layers reduce the exotherm of each layer. In addition, since the layer contracts when it returns to ambient, the shrinkage associated with layer pouring is decreased since only the top layer is involved. For example, if the coefficient of expansion is 50×10^{-6} per degree centigrade, a 100 mm chock with an exotherm of 100°C above ambient would shrink 0.5 mm, whereas, if poured in five layers only the final 20 mm would be involved and the exotherm may only be 30°C above ambient resulting in a shrinkage of only 0.03 mm. Care must be taken when pouring in layers to ensure the chock does not warp.

Ideally the exotherm attained during initial cure should not be less than the anticipated service temperature since the rate of temperature rise to the service temperature can then be instantaneous if desired. In practice, on many occasions the exotherm will be less than the service temperature and care will be required the first time the material experiences the temperature rise to service conditions since this will in effect be a post cure heat treatment under load. As a guide the initial temperature rise of the material should not exceed about 5°C per hour if lightly loaded as in the case of main engine chocks; that is about 5% of the ultimate strength. This allows about 12 hours for the chock, not the engine, to reach the maximum allowable temperature of 80°C. For most common prime movers this will be adequate. However, problems might exist with very small engines which reach operating temperature within minutes rather than hours and where the exotherm has been low. In such cases the rate of temperature rise of the chock will be too quick to allow sufficient time for the resin to post cure and the degradation in properties with increased temperature will be greater than the improvement arising from the post cure. For other types of installation where the service loading is higher than for engine chocks a lower rate of temperature rise may be necessary if deformation of the chocks is to be avoided. Ideally, of course, post cure should be carried out in the unloaded condition, but this is seldom practical even if a sufficiently large heat source were available.

It is normal to accept chocks on the results of tests on a small sample cast separately at the same time and with the same material as the chock. These samples are quality control samples of the material and the mixing. Tests carried out during approval will have ensured that, under all normal conditions, a sufficient degree of initial cure will be achieved and that subsequent heat treatment from the more usual types of engine encountered in the marine field will satisfactorily post cure the chock by the heat generated from the engine during the initial run-up to the service temperature of the chock. Tests on such samples seldom, if ever, reflect the properties of the chocks themselves in the *as cured* condition. In the first case, for reasons already mentioned regarding chock size and mould heat sink effect, the samples are unlikely to have the same exotherm

as the chocks and, therefore, are not representative of the chock. Secondly, the tests are normally carried out at a laboratory temperature of 20°C and the results, therefore, do not reflect the properties at service temperatures of 60°C or 80°C. Thirdly, if the sample exotherm were low for some reason, say 15°C, when taken to the laboratory the ambient air temperature of the laboratory at 20°C would post cure the samples to 20°C. In this respect if samples are ever to be tested they must never experience higher temperatures at any time prior to the test than the material they represent or the results will be invalid.

If the properties of any resin casting are of specific interest the only method of assessing them is to measure the exotherm and from correlated data obtain the relevant properties. Digital thermometers with thin needle probes are now available and should be used if at all possible. By greasing the probe and inserting it at half the depth immediately after pouring, the temperature within the chock can be monitored and the exotherm obtained.

In a chocking situation, if the exotherm is taken from the thinnest, and also the thickest chock if widely different, and is found to be acceptable, then if the chocks have been cast under stable conditions all the exotherms in the area will be satisfactory.

5. APPROVAL REQUIREMENTS

When resin chocks were first proposed it was realised that unlike traditional materials resin chocks might be affected by service temperatures. In view of the fact that little was known about the operating temperatures induced in chocks, surveyors from the Society's Technical Investigation Department, who regularly sailed worldwide in connection with their duties, were requested to record temperatures from chocks in-service together with other relevant information such as return oil, engine room and sea water temperatures. From the data collected it became obvious that engine, gearbox, shaft bearings etc., never exceeded 60°C even under the most arduous conditions. The temperatures recorded from steam turbine chocks and the like indicated that this was one area in which resin chocks would be unsuitable.

Data on engine weights, holding down bolt loads and oil temperatures obtained from manufacturers, together with the thermally associated mechanical properties from the resin manufacturers, indicated that if the loading on the resin was limited to 2.5 MPa then the resin might have creep characteristics which would be acceptable while at the same time being reasonable in the amount of resin required. It was, therefore, considered that any resin proposed for resin chocks, apart from being a practical proposition to cast in a marine environment, should also be capable of withstanding 2.5 MPa at 60°C without significant creep and should not be deleteriously affected by long service conditions. Subsequently, however, after many ship years of service, and arising from engine requirements for higher holding down bolt loadings and higher return oil temperatures, the requirements for some engines were increased to 3.5 MPa at 80°C.

In view of the ease of application and the satisfactory service, chocking materials are now used for a variety of purposes in the marine field from cryogenic applications to the installation of sterntubes.

The requirements for approval of chocking material to be used where alignment is critical has now been formalised and is shown in the Appendix. As stated the tests may be carried out at any recognised laboratory, but experience has shown that unless the laboratory or the manufacturer has practical experience of the marine field, the concept of it being necessary to consider the effect of entering service with properties associated with partial cure is overlooked. This oversight can cause considerable delays with incurred cost in the search for approval. The tests at the Society's Laboratories are comprehensive and should lead to the production of satisfactory resin chocks.

6. LABORATORY INVESTIGATIONS

6.1 Relevant Approval Tests and Typical Results

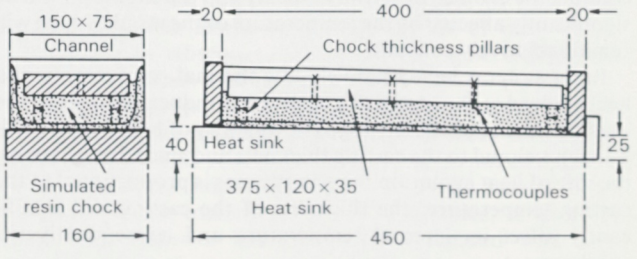
The investigations were conducted in order to determine whether specific resin systems would be suitable for use in a marine environment, would be practical and would be acceptable to the Society as chocks for machinery where alignment was critical.

The tests associated with plastics are in many cases used for comparison purposes only. International and national standards for plastics, such as part 35 of American Society for Testing and Materials (ASTM), are therefore very specific in sample preparation, conditioning, testing procedures and machines, reporting etc., and enable the results from one resin system to be compared with another. However, resin chocks in the marine field were a new development and since there was nothing to compare them with, tests were conducted in the spirit of the appropriate standard but the actual test procedure was modified to enable results to be obtained which could be used in practice, as well as for comparison purposes. The tests considered necessary demanded the manufacture of test equipment that would yield practical results.

In view of the proposed use of the resin system, the initial consideration was to ensure that a satisfactory chock could be cast in a marine environment and that sufficient exotherm would be achieved to obtain a degree of cure which would provide adequate mechanical properties of which compressive strength, creep, the temperature at which significant deformation would occur and the resistance to corrosion from oils and water were considered important. The flammability and the ability to withstand shock loads (i.e. the toughness) were also of interest.

In order to investigate the ability to cast a suitable chock and to obtain some idea of the exotherm to be expected in practice the test mould shown in Fig. 1 was manufactured. The thickness of material was chosen to reflect the heat sink and the gap at the sides of the top plate to simulate pouring situations which would be found in practice. The thickness of the simulated chock is determined by the length of the 5 mm diameter support pillars at the corners of the top plate. The exotherm is recorded by three thermocouples at the half and quarter lengths of the centreline of the chock which are inserted for half the chock thickness through small holes in the top plate.

It was appreciated that resin casts shrink on curing due, in part, to the chemistry and also to the thermal contraction as the chock cooled from the exotherm temperature to ambient. In



Dimensions in mm

Fig. 1 Steel mould for simulated chock

order to measure the curing shrinkage moulds as shown in Fig. 2 were constructed. Essentially two heavy circular end plates were surface ground and these were held apart by two thin walled semi-cylindrical spacers. As the exotherm varies with the mass of curing resin, various spacers from 12.5 mm to 100 mm were constructed. The exotherm was measured by thermocouples and when the moulds returned to ambient temperature a comparator dial gauge was used to obtain the shrinkage. This gauge gave a 0.0025 mm/div. reading on the cardinal points of the end plate with and without the spacers *in situ,* the end plates being under controlled pressure from the central bolt. The circular moulds also produced castings when the mould was immersed in water and also when it was placed in a heated oven at controlled temperature.

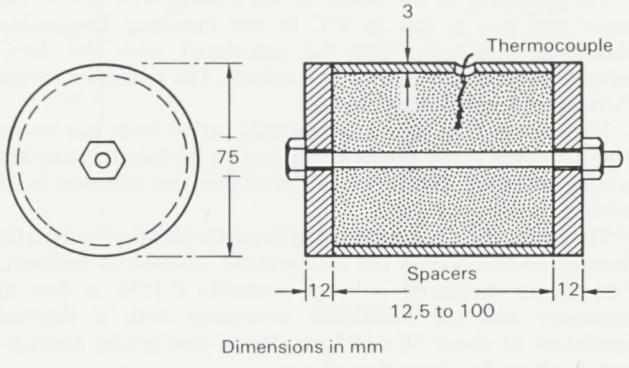


Fig. 2 Steel mould for exotherm and curing shrinkage

From these tests information on the ability to cast a chock and an indication of the range of exotherms which might be expected to occur in the marine field were obtained.

Test specimens for the various mechanical tests were machined from the castings from both moulds. This proved time consuming and expensive. Subsequently, it was found possible to produce test specimens which could be conditioned to the same degree of cure as those from the moulds. Aluminium moulds were used which because of their size relative to the casting and their high thermal conductivity enabled specimens with low exotherms to be produced. It was found that higher exotherms could then be simulated by post cure heat treatment for 4 hours in a temperature controlled oven at defined temperatures. This method also saved considerably on the amount of resin used for the large number of test specimens required to compliment the results of the limited number machined from the castings.

Tests to determine the mechanical and physical properties were conducted in the spirit of recognised national standards, predominantly those of ASTM. In order to facilitate the production of test specimens, all specimens were right cylinders except for deflection temperature, D648, and impact, D256, tests where rectangular prisms were used. The cylinders were 20 mm dia. $\times$ 25 mm, and rectangles either 12.5 mm $\times$ 6.25 mm or 12.5 mm $\times$ 12.5 mm cut to the required length.

Tests to determine the ultimate compressive strength were conducted over a range of temperatures from $-196°C$ to $+100°C$. At each test, the test specimen was immersed only for sufficient time to reach test temperature throughout (checked by a centrally embedded thermocouple on occasions) before commencing the test. The compression test was carried out on a universal servo-hydraulic testing machine.

These tests were extended to investigate the rate of induced strain at compressive stresses which were only a few per cent of the ultimate, thereby, defining the creep behaviour. In view of the length of the tests, up to one year, and the lack of suitable commercial equipment it was decided to construct the creep machines at the Society's Laboratory. Details are shown in Fig. 3 indicating that the machines are of the deadweight lever type, applying the compressive load through ball bearings and plattens, with a micrometer clock outside the cabinet. The cabinet is temperature controlled to within $\pm 1°C$ and an internal fan circulates the air to maintain temperature stability. Temperature sensitive items of the measuring equipment are of invar and the machines are frequently calibrated using invar test specimens.

The cylindrical test pieces are used in the oil and water absorption tests to D570. These tests are continued for long periods to determine if the chock would be affected in service. During these tests it was found that hydraulic oil had the greatest deleterious effect on epoxy resins. This oil was subsequently used in testing all materials.

The deflection temperature under flexural load, often referred to as the heat distortion temperature, is determined according to D648. A 12.5 mm $\times$ 6 mm prismatic beam is immersed in fluid and subjected to specified three point bending over a 100 mm span as the fluid temperature is increased at 1.8 to 2.2°C per minute. When the central load deflects 0.25 mm, the temperature of the fluid is the deflection temperature.

The same specimens were used to assess the rate of burning according to D635. On withdrawing from the blue bunsen flame after 30 seconds the material extinguished itself with little scorching.

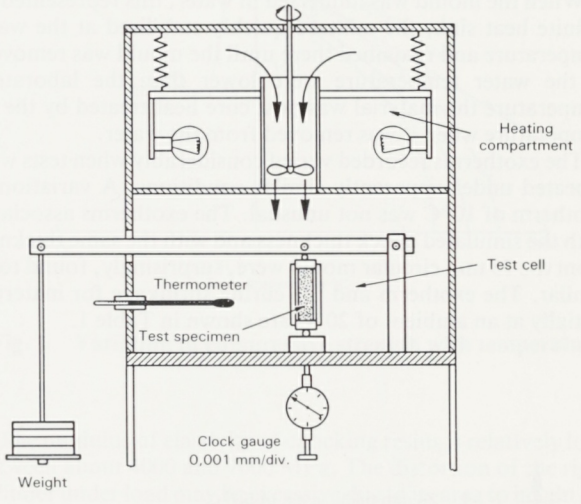


Fig. 3 Creep cabinet

6.2 Experimental Results

The variation in results from materials cast under apparently identical conditions, often from test specimens machined from the same block, were such that a statistical approach had to be made. For example, an exotherm from two mixes might vary by $\pm 5°C$ and the compressive strength of two specimens machined from the same block might vary ± 5 MPa. The only test considered repetitive was the deflection temperature at $\pm 1°C$.

The material is considered satisfactory for casting if it can be easily mixed and poured through the 15 mm gap between the mould side plate and top plate so as to produce a close tolerance casting with no significant air trapped under the top plate, thereby, producing cratering of the surface.

The curing temperature, monitored continuously during curing, indicated that the exotherm increased with chock thickness and varied substantially between resin systems. The range of exotherms recorded varied from between 25°C to 30°C

for a chock thickness of 12.5 mm to between 50°C to 125°C for a 35 mm chock. The period between pouring and attaining the exotherm also varied from 4 hours to 45 minutes. It was also noted that, prior to pouring, the temperature of the mixture gradually increased from the laboratory ambient of 20°C to 24°C due to initiation of the curing process, but that its temperature was reduced within a few minutes to that of the mould when it was poured. The subsequent rate of increase then depended on the chock thickness and the particular resin used. Typical temperature time curves are shown in Fig. 4 for the type of moulds shown in Fig. 2.

In order to investigate the other parameters which were thought to effect the exotherm, the moulds shown in Fig. 2 were used. Whilst it was appreciated that these moulds would not be representative of full scale practice with respect to the mass ratio of resin to mould, it was considered that useful indications of the trends to be expected in practice would be obtained. These moulds used far less resin than the simulated chock mould so one mix could be used to fill a number of similar moulds varying one parameter at a time.

The effect of thickness was investigated by increasing the length of the spacer from 12.5 mm to 25, 35, 50 and 100 mm; the 12.5, 25 and 35 mm were also the thicknesses of the simulated chock. The effect of ambient temperature could be assessed by immersing the mould in water or heating it in a thermostatically controlled oven, to simulate either northern winters or alternatively tropical dry dock conditions. The effect of heat sink size could be assessed by increasing the number of end caps.

When the mould was immersed in water, this represented an infinite heat sink, the mixture quickly stabilised at the water temperature and remained there until the mould was removed. If the water temperature were lower than the laboratory temperature the material was post cure heat treated by the air temperature when it was removed from the water.

The exotherms recorded varied considerably when tests were repeated under apparently similar conditions. A variation in exotherm of 10°C was not unusual. The exotherms associated with the simulated chock thickness and with the same thickness from the 75 mm circular mould were, surprisingly, found to be similar. The exotherm and the curing shrinkage for materials initially at an ambient of 20°C are shown in Table 1.

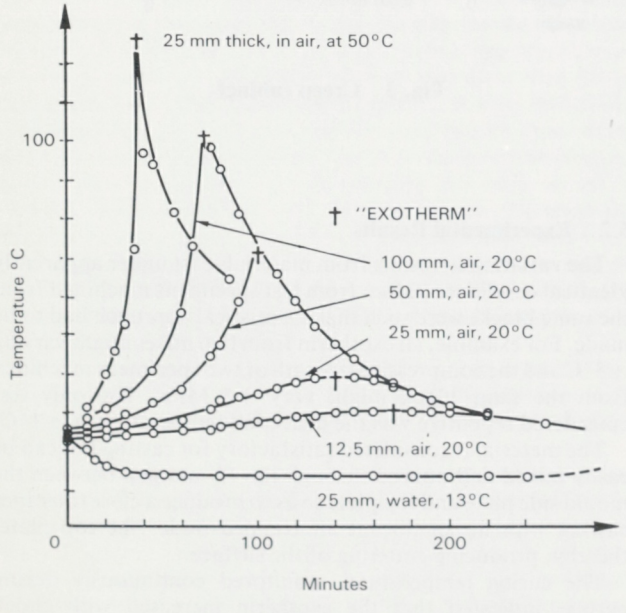


Fig. 4 Typical temperature versus time curves

Resin Type	A				
Thickness mm	12.5	25	35	50	100
Exotherm °C	30	40	50	70	100
Curing Shrinkage %	.21	.28	.34	.42	.55

Resin Type	B		C		D	
Thickness mm	12.5	35	25	35	25	35
Exotherm °C	30	45	40	110	30	100
Curing Shrinkage %	.25	—	.17	—	.31	.55

Table 1 Exotherm and curing shrinkage for materials initially at 20°C

The exotherm of the water cooled moulds was that of the water and was as low as 9°C in one instance. The curing shrinkage, however, must be associated with the 20°C laboratory environment (i.e. post cured). The minimum curing shrinkage recorded was 0.16%.

The exotherm of the heated moulds varied from just under 100°C to over 175°C the latter registering the highest recorded curing shrinkage of 0.69%. The exotherm was achieved in 15 minutes in one case.

The curing shrinkage appears to be partly chemical and partly thermal contraction as the temperature returned to ambient. The values measured indicate probably 0.15% is due to chemistry and the remainder associated with a thermal coefficient of about 50×10^{-6} per degree centigrade; approximately about five times that of steel.

Like most materials the mechanical properties of chocking resins increase with decrease in temperature. Toughness, however, remains relatively constant unlike steel. The opposite trend, namely that of the properties decreasing with an increase in temperature, is also true but requires amplification since above ambient the properties also depend on the degree of cure. The effect of cure can probably best be appreciated by considering the effect of temperature on the material when under load.

6.2.1 Deflection Temperature of Plastics under Flexural Load ASTM D648

This relatively simple test proved very revealing. The results of repetitive test on similar specimens were within ±0.5°C. No other tests give results with such close agreement. If the heating continued after the deflection reached 0.25 mm the beam deformed drastically before the temperature had increased by half a degree. The test specification allows the central load to induce a maximum bending stress of 0.455 MPa or 1.82 MPa, a ratio of four to one, yet the resulting difference in the deflection temperature never exceeded 4°C.

As mentioned earlier, even under identical conditions, exotherms are not reproducible with any degree of accuracy. Post cure heat treatment of specimens can be controlled to within ±1°C with little difficulty. To obtain identical specimens and specimens which would cover a wide range of cure, specimens were cast in aluminium moulds so that low exotherms would be obtained. The exotherms were reduced below the laboratory controlled ambient and the specimens subsequently post cured by exposure to the ambient temperature for some days. Various batches of specimens were further post cured in temperature controlled ovens, ±1°C, for 4 hours until sufficient specimens were available with post cures at temperatures in 10 degree increments between 20°C and 120°C. This technique was used for all test specimens but even then variations in results occurred except for the deflection temperature results.

The temperature deflection results are shown in Fig. 5. All the systems tested produced transition type curves, that is, at low post cure relatively constant deflection temperatures were

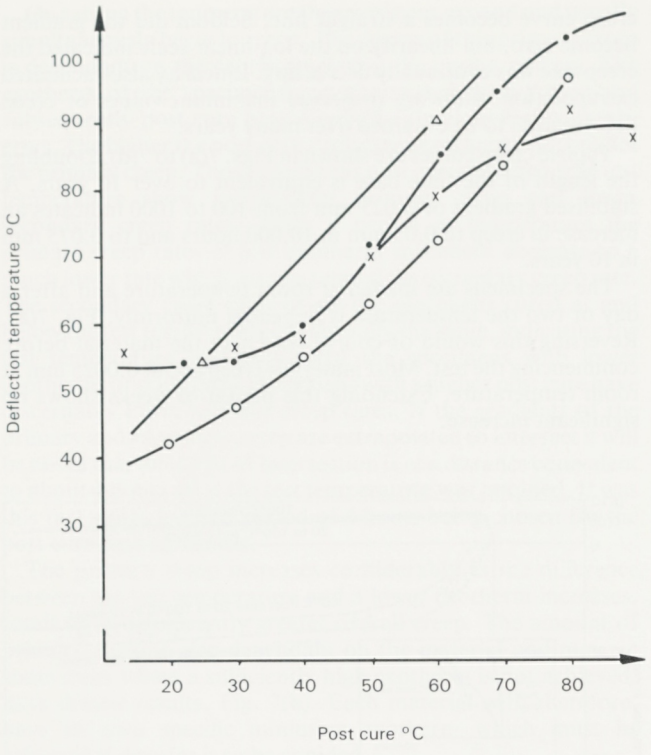


Fig. 5 Temperature deflection for various resins

obtained. Then came a range of post cure temperatures which were associated with increasing deflection temperatures with increase in post cure and finally a range of increasing post cure temperatures which produced no significant increase in the deflection temperature.

In addition to controlled post cure tests, tests were conducted on specimens with a range of natural exotherms. This enabled an approximate correlation to be obtained between an exotherm and an equivalent post cure. For example, a specimen with an exotherm of 82°C realised a deflection temperature of 93°C whereas the same material with an exotherm of approximately 30°C and subsequently post cured for 4 hours at 80°C realised 97°C. A high exotherm produces a temperature-time curve similar to a resonance curve with a time base much less than 4 hours. It would appear, therefore, that a material with any specific exotherm will have properties similar to a material post cured at a temperature 5 to 10°C lower. If the effect on deflection temperature is reflected in other properties the improvement from increased exotherm, or post cure, is obvious.

To investigate if the same improvement can be achieved with the passage of time at lower post cure temperatures a number of specimens were prepared simultaneously with exotherms below room temperature, stored at room (post cure) temperature and periodically one of the specimens would be tested. Over a period of six months the deflection temperature increased from 51.6°C to 54°C, but even towards the end of the period a value of 52.6°C was recorded. This tends to indicate that after initial cure no significant increase in cure occurs with time. The increased values could well have been associated with increases of one or two degrees in storage temperature.

6.2.2 Compressive Strength

Twenty millimetre diameter specimens were compressed along their 25.4 mm axial length. Specimens were tested with varying degrees of cure by post cure heat treatment of the specimen. Immediately before the test the specimens were immersed in fluid at the test temperature. By means of a centrally embedded thermocouple it was found that less than 10 minutes immersion was required before the whole specimen had attained the test temperature. It is considered this period is insufficient to induce post curing.

The results are shown in Fig. 6. These indicate that the compressive strength decreases with temperature, but more importantly they indicate that if the test temperature is much greater than the exotherm, or any previous post cure temperature, then the compressive strength is significantly less than the value which would have been obtained if the exotherm or post cure had been greater than the test temperature. The significant point of these tests is that if a sample is abstracted from a casting and tested at room temperature the results will give no indication of the suitability of the casting for use at temperatures higher than the exotherm or post cure. The variation in results from identical specimens was similar to the difference between 25°C and 80°C post cures when tested at 20°C.

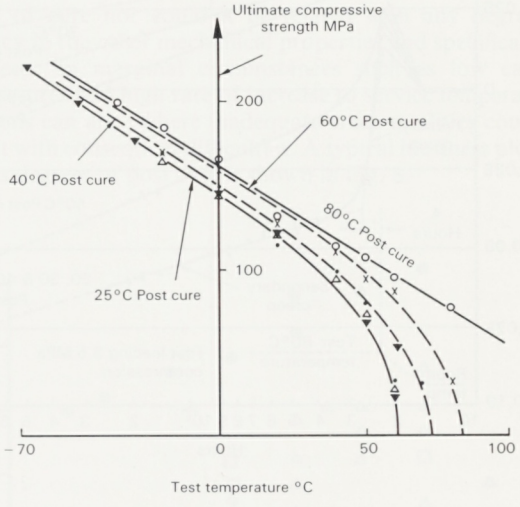


Fig. 6 Variation in compressive strength with temperature

The modulus of elasticity of chocking resins is relatively low, between about 4000 and 7000 MPa. The distortion of the right cylinder under load may be excessive due to its area to height, or thickness ratio. Supplementary tests on various area to thickness ratios were, therefore, conducted. A 12.5 mm thick and a 25 mm thick chock were cut-up into 25, 50 and 75 mm squares. The ultimate compressive strengths (U.C.S.) measured are shown in Table 2.

The average value of the U.C.S. of a 20 mm diameter × 25 mm specimen is about 125 MPa. It would appear that the ultimate crushing strength for area-thickness ratios, greater than 50, may be of the order of 200 MPa for a fully cured resin. In view of the effect arising from partial cure a safety factor of 2 would appear appropriate, thereby, reducing the ultimate compressive strength to around 100 MPa.

Thickness mm	12.5		
Chock Size (mm × mm)	25 × 25	50 × 50	75 × 75
U.C.S. MPa	135	170	193

Thickness mm	25.0		
Chock Size (mm × mm)	25 × 25	50 × 50	75 × 75
U.C.S. MPa	117	135	145

Table 2 Variation in ultimate compressive strength

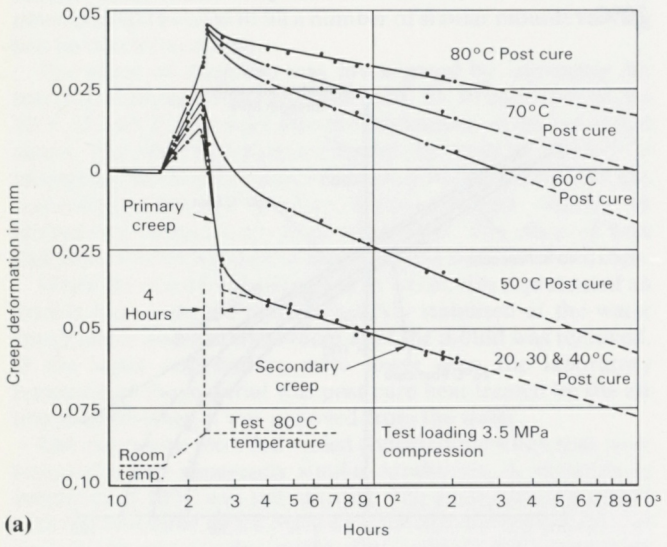
6.2.3 **Creep**

The creep requirements for chocking resins is strict in order to avoid crankshaft alignment problems. For approval the maximum creep deformation allowed over the test period of 4000 hours is less than 0.1 mm and involves measurements to within 0.001 mm. Due to variations inherent in any material, identical results of such a precise nature from two identical specimens is virtually impossible to achieve. A statistical approach is, therefore, required and trends are of primary importance.

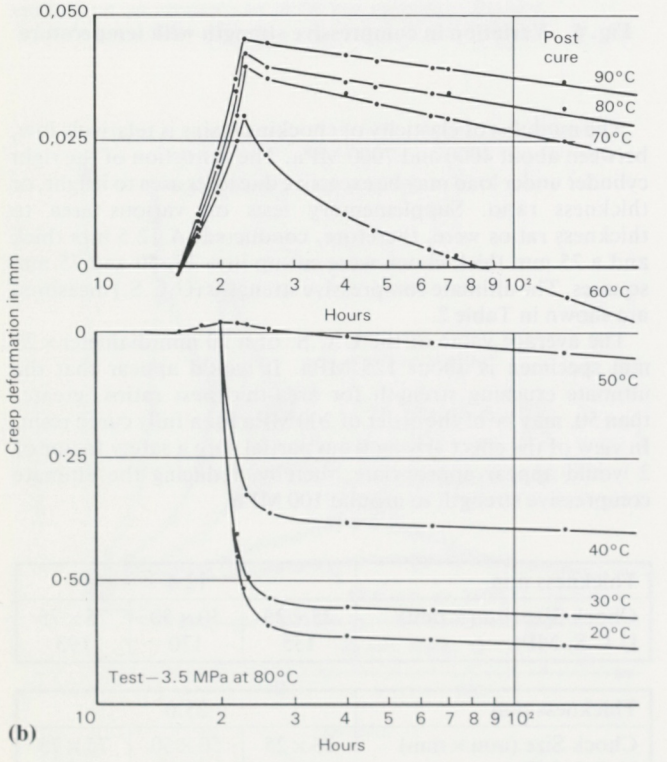
With most resins the maximum creep rate occurs in the first few hours and after a few hundred hours the creep rate stabilises. The time increment between readings is, therefore, small initially but increases with the passage of time, thereby, making a logarithmic time base convenient. If the creep deformation is plotted linearly it was found that eventually the creep curve becomes a straight line. Seldom did the gradient become zero, but linearity on the log-linear scale indicated the creep rate was continually decreasing. Linearity also facilitated extrapolation, allowing projected maximum values of creep deformation to be obtained over many years.

Typical creep curves are shown in Figs. 7(a) to 7(d). Doubling the length of the time base is equivalent to over 10 years. A stabilised gradient of 0.025 mm from 100 to 1000 indicates an increase in creep to 0.05 mm in 10,000 hours and to 0.075 mm in 10 years.

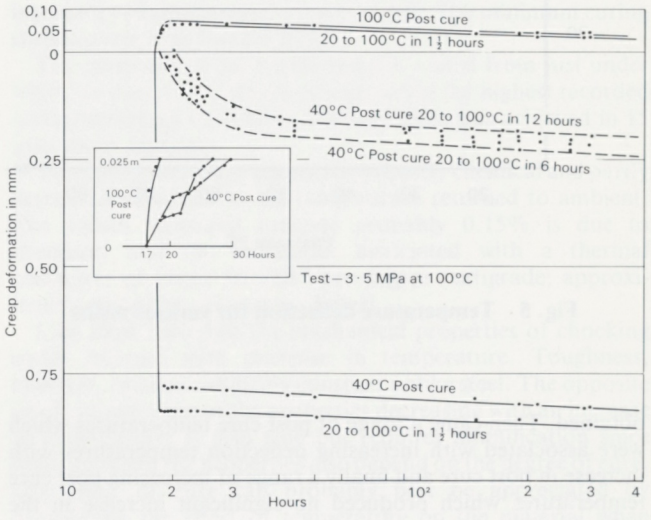
The specimens are loaded at room temperature and after a day or two the temperature is increased uniformly, Fig. 7(a). Reversing this would of course post cure the material before commencing the test. Most materials creep about 0.0025 mm at room temperature. Extending this period to weeks shows no significant increase.



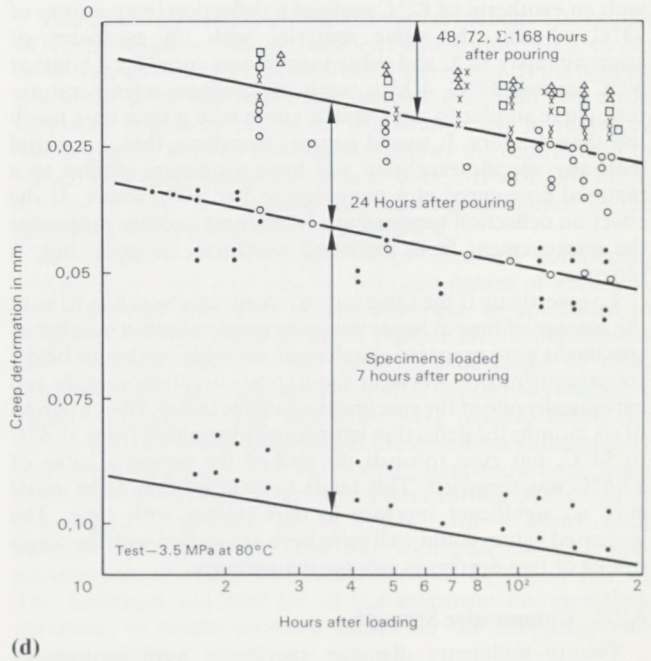
(a)



(b)



(c)



(d)

Fig. 7(a)–(d) Typical creep deformations

On raising the temperature the specimens expand and usually simultaneously begin to creep. The degree of this primary creep is dependant on the exotherm during the curing process. The exotherm of the specimens was suppressed during cure and subsequently post cure heat treated to simulate higher exotherms. The higher the post cure, simulated exotherm, the smaller the primary creep. Those specimens post cured to above the test temperature show insignificant primary creep and lower secondary creep rates. After a period at temperature the primary creep rates of low exotherm specimens decrease to a much lower rate which may be termed the secondary creep rate. The secondary creep rates of all the specimens cured at and below the test temperature are virtually the same, indicating the test temperature has post cured the specimens with lower exotherms or post cures. Specimens with a higher post cure have discernably lower primary creep rates. If the gradients of the primary and secondary creep are extrapolated to intersect it will be noted that the point of intersection is at a distance equivalent to about 4 hours after the test temperature was attained. It was this fact which led to a period of 4 hours being chosen for the post cure heat treatment.

The primary creep increases considerably as the difference between the test temperature and a lower exotherm increases, resulting in significantly greater overall creep. The amount of primary creep is also dependant on the material and may, in some cases where a sufficiently high exotherm is not achieved, have drastic results, Fig. 7(b). Each material will, therefore, have its own specific minimum exotherm which must be achieved if disaster is to be avoided.

Approved materials which require a higher exotherm than others usually attain a higher exotherm in similar situations due to their composition.

A factor that will affect all materials is the rate of service temperature increase. For example, if it takes 4 hours for a material to post cure obviously an increase in temperature in 1 hour will have drastic consequences. In Fig. 7(c) various rates of temperature increases are shown. In order to obtain high deformations, much higher than normal test temperatures were used. A temperature rise of 60°C per hour caused a drastic primary creep which, however, then reduced to a more normal rate of secondary creep. Extending the length of time over which the temperature rose to 6, 9, and 12 hours caused a much smaller primary creep and approximately the same secondary creep. The total creep of the specimens raised in 6, 9, and 12 hours, giving temperature increase rates of 15, 10 and 7.5°C per hour, was not significantly different. Subsequent tests with various resins tested to the test temperature indicated that a rate of temperature rise of 10°C or less should give no cause for concern. The upper curve on Fig. 7(c) shows that if the material has been post cured to at least the test temperature then a 60°C per hour temperature rise will be satisfactory.

Finally, tests were conducted on partly cured specimens, Fig. 7(d). These were moulded to size and limited to an exotherm of 25°C. The specimens were loaded as before, 3.5 MPa at a room temperature of 21°C, at periods after pouring of between 7 and 168 hours. At 21°C no significant difference occurred when loading was restricted to a minimum of 48 hours after pouring.

6.2.4 Hardness Measurements

Barcol hardness is used in the plastics industry as an indication that cure has taken place. The Barcol Hardness Tester is held in one hand and the three feet pressed against the surface to be measured. One foot has a co-axial spring loaded needle connected to an integral dial gauge. The penetration of the needle into the surface is measured direct from the dial as the Barcol Hardness. With filled chocking resins the hardness can be influenced by the filler and the reading decreases with time of penetration. In the plastics industry 'flick' readings giving the maximum are the norm, but with chocking materials it was considered more consistent readings could be obtained after an interval of 15 secs.

When resin chocks first were proposed Barcol Hardness Testers were not normally to be found in shipbuilding and repairing yards unless glass reinforced plastics were manufactured. Brinel hardness, however, was a familiar instrument. The anticipated hardness of resins is much lower than that of ferrous materials and under the normal Brinel loads the ball was driven into the cast material. The Brinel loads were, therefore, reduced to 250 kgf with the more common 5 mm ball or 500 kgf with a 10 mm ball. The cast resin does tend to 'flow' under these loads and the diameter of the depression can be difficult to assess accurately due to the flow lip formed by the deformed plastic.

Subsequent investigations over the years gave hardness readings which varied considerably with a scatter such that no real indication of the degree of cure could be deduced from the hardness readings. All that could be assessed from the hardness was that the cure obtained indicated the resin system had been mixed adequately. Since the resin system had been approved as suitable for use in a marine environment, in the majority of cases this test was adequate. It did not, however, indicate the degree of cure nor could it be related with any degree of accuracy to the other mechanical properties and specifically to the creep. In marginal circumstances such as low casting temperatures and high rate of increase to service temperature, situations can arise where inadequate creep qualities could be present with consequent difficulties. A typical hardness plot for various degrees of post cure is shown in Fig. 8.

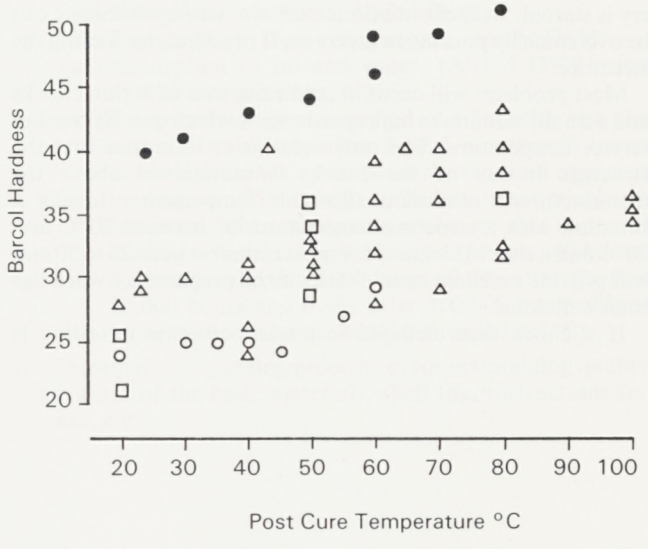


Fig. 8 Typical hardness versus post cure variations

6.2.5 Toughness (Impact)

The toughness of the resin at room temperature proved to be low with an Izod value of about 1 Joule at room temperature for an Izod specimen devoid of the notch having a 10 mm × 10 mm plane cross section and fully cured. The Izod varied with cure from 0.4 to 1.2 Joules. When heated to service temperature the impact value increased to about 1.5 to 2 Joules. This is a severe test. A drop test showed no tendency to brittleness.

6.2.6 Flammability

Resin chocking materials have been found to be self-extinguishing when removed from the flame of a bunsen burner.

6.2.7 **Absorption**

Samples of 20 mm diameter by 25.4 mm long were immersed in various oils and water. The greatest absorption took place in water and the type, salt or distilled, made little difference. After 24 and 72 hours the percentage absorption by weight was .03 and .06 respectively soon after which the absorption rate stabilised at 0.15% per 1000 hours. The worst of the oils was found to be hydraulic oil. After 24 and 72 hours the oil absorption was 0.021% and 0.025% and this stabilised at 0.045% per 1000 hours.

Creep measured from specimens immersed in hot oil and hot water showed no cause for concern after 1 year and in fact the measured values were slightly better than those in air.

7. CONCLUSIONS

Provided an approved chocking resin is mixed and poured carefully in temperatures above the manufacturer's minimum a satisfactory chock will be obtained. Problem areas which might arise will be from pouring too thick a chock in too warm a situation or alternatively a medium to thin chock in a cold area where the temperature of the heat sink is below the manufacturer's recommendations. The latter difficulties will be compounded if the chocks are under a small engine which could attain service temperature in a very short time.

Where curing temperatures are too high a chock with excessive curing shrinkage could occur, although this will be offset by a chock with little primary creep. Curing shrinkages, if excessive, should be detected by alignment before the machinery is started. In such situations excessive curing shrinkage can be overcome by pouring in layers or, if practical, by cooling the structure.

Most problems will occur in cold situations with thin chocks and a small, medium to high speed engine which quickly reaches service temperature. The only solution is to ensure that the structure in-way of the chocks is maintained above the manufacturer's minimum allowable temperature. Ideally a situation with a structure temperature of between 20°C and 30°C and a chock thickness for most resins between 25 to 50 mm will provide excellent resin chocks if the preparatory work has been well done.

If a chock does collapse in-service subsequent testing is virtually useless since the chock will have been post cure heat treated by the service temperature and any subsequent material mechanical properties measured will bear no resemblance to the mechanical properties existing at the time of the failure.

Quality assurance specimens cast concurrently with the chock will only reflect the chock properties if the specimen and the chock attained the same curing temperature. Otherwise the specimen will only indicate that the material is correctly mixed and of the correct composition. The chocks should still prove adequate since the properties of an approved resin chocking system mixed and poured in the extremes of temperature likely to be met in the field, has been shown to be fit for the purpose. If, however, the temperature conditions are outside the normal, the only method of ensuring satisfactory chocks is to monitor the temperature at the centre of the thinnest part of the chock and compare the exotherm with that obtained during laboratory tests to obtain the related mechanical properties.

Digital thermometers reading from − 100.0°C to 200.0°C are now on the market. They are supplied either with a needle probe which can be greased and pushed into the chock before it gels, or with thermocouple wire which can be inserted and supported at any desired position before pouring and can subsequently be cut flush with the chock after the measurements.

The cost of such measurements today are only a few pounds and much cheaper than a Barcol tester, about one tenth the price if limited to the more practical range of 0 to 100°C.

Resins approved for chocking situations are also used in many other areas. Provided the castings reach a minimum exotherm, which should be available from the manufacturer, the mechanical properties quoted by the manufacturer will be obtained at any temperature below the exotherm. It is only when the material operates at high temperature for the first time that problems can occur on that occasion. Provided the material is held at temperature for a sufficient time for a post cure heat treatment to take place subsequent rapid variations in temperature can be accommodated provided they do not significantly exceed the previous maximum temperature.

8. ACKNOWLEDGEMENT

The author would like to express his appreciation for the help and enthusiasm of Mr. Douglas Stone.

APPENDIX

GUIDE TO THE APPROVAL OF EPOXY RESIN CHOCKS WHERE ALIGNMENT IS CRITICAL

Experience indicates that for satisfactory operation of resin chocking material it must be capable of sustaining, without appreciable creep, a compressive load of 2.5 MPa (350 lb/in^2) at a temperature of 60°C (140°F) when cast under practical conditions, that is in the presence of a massive heat sink at ambient temperature. Temperatures and loadings above the minimum are at the discretion of the manufacturer, current maximums are 80°C and 3.5 MPa.

Approval by the Society for resin chocking material may be given on evidence of independent laboratory tests or by laboratory tests carried out under the supervision of the Society's surveyors. The facilities of the Society's Laboratory are available for which a fee is charged. Experience has indicated that the latter is the most expeditious route to approval.

Laboratory tests should be carried out, where applicable, in the spirit of internationally accepted standards (i.e. ASTM, BS, DIN, ISO etc.).

The test specimens *must* be representative of the material used in practice with regard to curing and must not be post cured. Due to the massive heat sink of engine and seating at ambient temperature the exotherm is often restricted and since post cure heat treatment is seldom practical, the maximum physical properties are seldom achieved before initial service.

In order to obtain approval, the following information is required:

1. Proof of satisfactory application.
   - (i) Pourability.
   - (ii) Maximum and minimum allowable thickness per pour (12.5 mm is the normally acceptable minimum chock thickness. Maximum depends on exotherm and curing shrinkage).
   - (iii) Allowable temperature limits for mixing and pouring.
2. Particulars of curing cycle.
   - (i) Time to obtain complete cure at ambient temperatures.
   - (ii) Particulars of exotherm in association with a massive heat sink as will be present between engine and ship's structure. (For various ambient temperatures and thicknesses of pour within the manufacturer's recommended range).
   - (iii) Curing shrinkages associated with exotherm variations.
3. Corrosion resistance.
   - (i) Of resin filler (not metal filling pieces to conserve resin).
   - (ii) Of cured material to salt water, fuel, lubricating and hydraulic oils, etc.
4. Physical properties of material with minimum exotherm acceptable in practice (for information only, typical values found in laboratory tests are bracketed).
   - (i) Compressive strength and modulus of elasticity. (With 25 mm high by 20 mm diameter column specimen, 120 and 3500 MPa respectively).
   - (ii) Brinell or Barcol hardness. (30 with 5 mm ball and 250 kg load, 35 Barcol).
   - (iii) Impact. (0.8 J on 12.5 × 12.5 mm Izod without notch).
   - (iv) Coefficient of friction with metal including any anti-adhesion preparation (0.5).
   - (v) Heat distortion (60°C, ASTM D648).
   - (vi) Flammability. (Self extinguishing, ASTM D635).
   - (vii) Absorption of oil and water. (ASTM D570 using 25 × 20 mm specimen, 0.05%).
   - (viii) Creep testing. Over a period of 6 months with the material stabilising after 2 to 3 months. (Various deadweight loads up to twice the required approval loading on a 25 mm high by 20 mm diameter column specimen with maximum creep at the approval loading not exceeding 0.1% after the first 100 hours, 0.2% after the first 1000 hours, 0.3% after the first 10,000 hours and 0.4% after 100,000 hours. Minimum test temperature 60°C controlled ± 1°C).
5. Information regarding procedures for maintaining quality control of the basic materials, shelf life, instructions for use, etc.

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THE ASSESSMENT AND CERTIFICATION OF CONTAINER SECURING ARRANGEMENTS ON BOARD SHIPS

J. A. Morris and A. J. Williams

Paper No. 3. Session 1984-85

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THE ASSESSMENT AND CERTIFICATION OF CONTAINER SECURING ARRANGEMENTS ON BOARD SHIPS

by

J. A. Morris and A. J. Williams

SYNOPSIS

In 1980, LR introduced "Requirements for Freight Container Securing Arrangements", on compliance with which a ship is eligible for the special features class notation "Certified Container Securing Arrangements".

This paper is concerned with the assessment of arrangements for the notation with the principal emphasis directed towards securing systems using loose securing equipment, such as lashings and twistlocks. Brief mention is made, however, of cell-guide structures.

The Society's assumptions regarding the motions of the ship are examined, together with the combination of these motions leading to the calculation of the static and dynamic forces acting on the containers in the stack. The failure mechanisms are discussed, including racking and crushing of containers, tipping and bursting of the container stack and failure of securing fittings. Alternative securing systems are illustrated and their application to different stack formations considered.

Aspects of the materials and design of fixed and loose fittings are discussed and illustrated.

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1. INTRODUCTION

The amount of cargo which is now transported on ships in containers forms a major proportion of the sea freight which is suited to be transported in this way. Considering this large volume of traffic, it is perhaps inevitable that incidents of damage to or total loss of containers and their contents have occurred. Increasing incidence of damage or loss in the last decade had, however, given rise to concern within the industry regarding the adequacy of container stowage and securing arrangements provided in some cases.

The Society's response to this concern culminated in the publication of formal *Requirements for Freight Container Securing Arrangements* in 1980 for assessing stowage and securing arrangements for containers on board ships. Compliance with these Requirements would lead to the assignment of a special features class notation "Certified Container Securing Arrangements". The Requirements are intended to encourage a standardised strength capability for securing equipment to ensure ready replacement and interchangeability. Assignment of the special features notation indicates that an independent examination of the container securing system has been carried out and that all elements of the system have been tested and approved.

In the subsequent sections of this paper, the current approval procedures and techniques are presented and discussed, but before proceeding it may be of interest to consider a little of the history in the development of the container and the fleet which transports them.

The container in its modern sense originated in the United States in the mid-1950's. Initially, the shipping companies developed their own standards for the strength and dimensions of containers to suit their existing ships' equipment and particular patterns of trade. It rapidly became apparent, however, that a consistent approach would be required to permit interchangeability of cargoes between stages of the transport route, and in 1958 the US Maritime Administration and the American Standards Association set up committees to consider container dimensions, construction and fittings with a view to standardisation.

With the increasing use of containers in the USA and later in other countries, it became apparent that international standardisation would be required and, in 1961, the International Standards Organisation committee ISO/TC 104 Freight Containers first met. Although the first comprehensive standard appeared in 1965, it was not until 1971 that the American and International Standards Institutions published the standards which now form the technical basis of the modern container.

The ISO Standards[1]* were revised during the 1970's to incorporate developments at that time. Development continues and, in certain respects, the standards have been overtaken by events. In particular, there has been a widespread introduction of the uprated 20 ft container of 24000kg gross weight, and it is possible that the next revision of the ISO Standards will take this into account.

In parallel with the development of technical standards, the need was recognised to regulate safety, handling, testing and maintenance of containers throughout the world. This aspect was pursued through IMCO which arranged a joint IMCO/ISO conference in 1972. The conference drew up the Convention for Safe Containers (CSC) which ultimately came into full operation as recently as September 1982.[2]

The standard unit of capacity in the industry is the Twenty Foot Equivalent Unit (TEU) or, in other words, the 20 ft container. One 40 ft container is equivalent to two 20 ft containers, and therefore is 2 TEU, sometimes referred to as 1 FEU. Statistics referring to capacity, from that of a particular ship to that of the total fleet, are generally given in terms of TEU's.

*Numbers in parentheses indicate references.

There is a place, of course, for containers of other lengths (35 feet and 45 feet in particular) and for special purpose designs from the flat to the tank. However, so much ancillary equipment, such as quayside cranes and handling vehicles, is designed for the standard box that it is unlikely these will lose their dominant position. On the other hand, as already mentioned, the rated weight (defined as the total weight of the container plus payload) is increasing, such that the 20 ft box is now commonly rated at 24 tons and there are indications that the 40 ft box may increase to 35 tons rated weight. This raises obvious problems in the lifting capacity of handling equipment and is also a factor to be considered in designing the on-board container securing system.

Most container ship operators are common carriers in the sense that they transport containers of any ownership, even though they themselves may own or lease a fleet of their own containers. It follows, therefore, that the stowage and securing arrangements in the ship must be suitable for any container complying with the CSC and ISO Standards. Consequently, these standards form the basis on which regulations for securing arrangements are framed.

The container carrying fleet has expanded steadily over the last twenty years and both the number and maximum size of ships has increased. There are now nearly 3000 ships designed for the carriage of containers, providing a total capacity of about 1,75 million TEU. Of these, some 30% are fully cellular container ships and a further 17% are Ro-Ro ships. The remaining 53% is made up of bulk carrier and multi-purpose cargo tonnage (Fig. 1) carrying containers on deck or in holds. About 50% of the fleet is no more than 5 years old. A broad breakdown is given in Table 1 and a more detailed analysis will be found in the literature.[11]

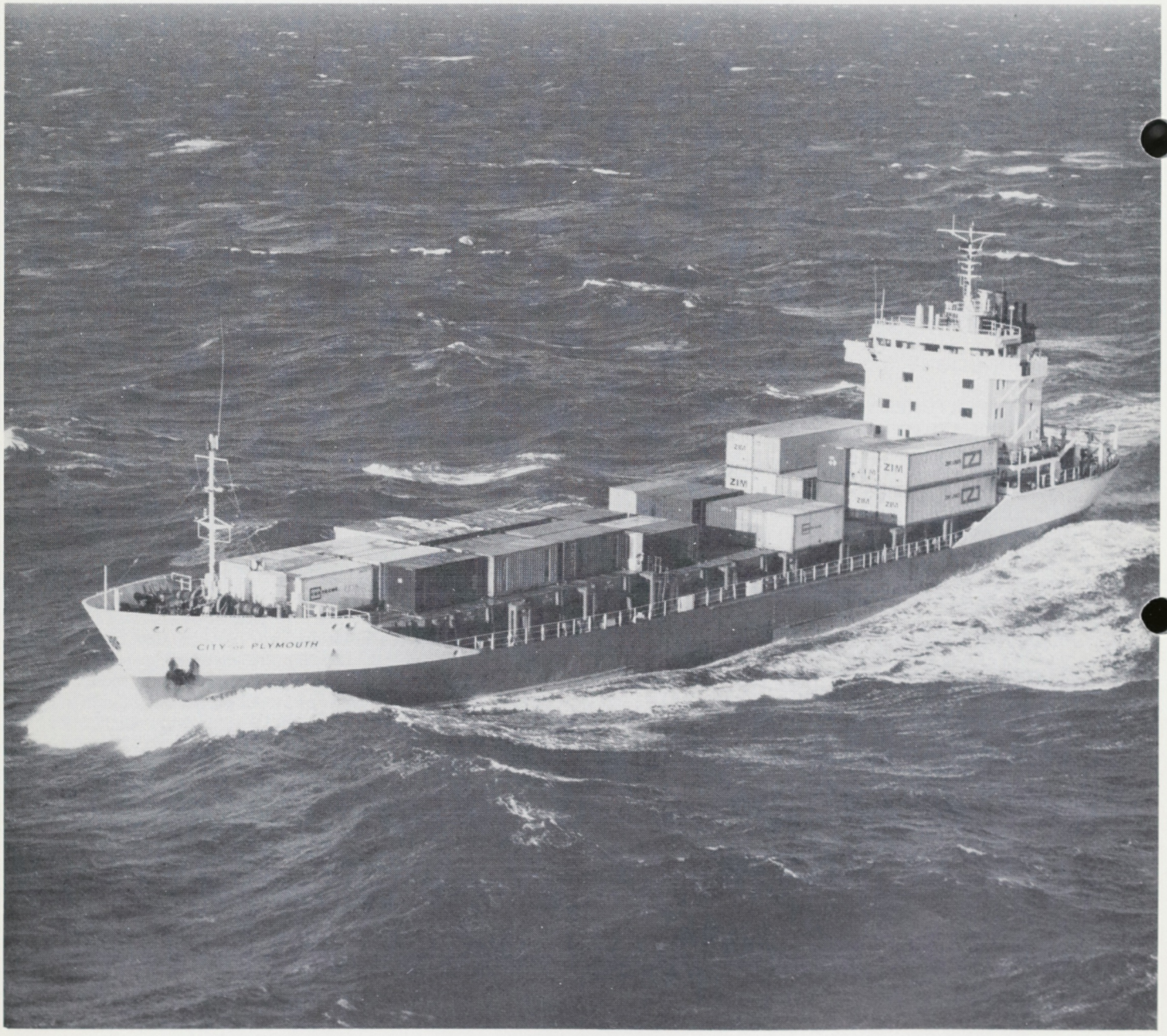


Fig. 1 A typical multi-purpose cargo ship carrying containers

Recent economic trends have forced owners to seek maximum flexibility in the operation of their ships, and there has been a considerable increase in the number of bulk carriers and cargo ships equipped also to carry containers on deck and in holds. Even some ship types which might be considered specialised have acquired a multi-purpose role. A number of refrigerated cargo ships ordered recently, for instance, are also designed to carry containers both on deck and in the holds.

In addition, there is a large number of cargo ships carrying containers as occasional cargo with a limited amount of specialist equipment. The Society has advised on a number of installations in this category.

Returning to the containers themselves, there are more than 3 million units in existence, totalling about 4 million TEU. An approximate breakdown of their principal characteristics is given in Table 2 and a detailed analysis will be found in the references.[11]

The average age of the world total of containers is just under 5 years and more than 90% is less than 10 years old.

The relative proportions of 20 ft and 40 ft boxes have remained roughly constant in recent years. The proportion of 8′ 6″ boxes, however, has increased to about 95% in the last 3 years and steel cladding is now used for nearly 90% of containers.

Table 1 World containership fleet at end 1983

Ship Type	TEU			Total	
	<1000	1000–2000	>2000	Ships	TEU
Cellular	492	330	73	895	882736
Ro-Ro	410	83	4	497	269238
Multi-purpose	1495	55	–	1550	588980
				2942	1740954

Source: Containerisation International, January 1984.

NOTE: In addition, there are orders for 310 ships totalling 329142 TEU, of which 39 cellular and 8 Ro-Ro ships will exceed 2000 TEU each.

Table 2 Container characteristics (percentages)

Length	20ft 71%	40ft 26%	Other 3%
Height	8ft 9%	8ft 6ins 87%	Other 4%
Cladding	Steel 77%	Aluminium 15%	Wood/GRP etc. 8%

2. SPECIAL FEATURES NOTATION AND CERTIFICATION

The Society first investigated the forces imposed on container cell-guide systems in the early 1970's as part of the plan approval and development work then under way in respect of cellular container ships. The stowage of the containers themselves was considered to be outside the scope of classification.

However, in response to requests from certain shipowners for advice, the Society prepared guidance notes on container securing arrangements at the end of the decade and these also encompassed non-cell-guide stowages.

The definition of ship's motions and the consequent imposed forces presented no great problems, but these had to be related to the type and strength of fittings and the factors of safety in securing systems which had been found to give a satisfactory performance in service.

Following extensive discussions with container securing equipment manufacturers, shipowners and others, *Requirements for Freight Container Securing Arrangements* were first published in 1980, and subsequent editions followed in 1981 and 1984.[3]

The special feature notation "Certified Container Securing Arrangements" is optional in the sense that the owner of a classed ship is not required to obtain the notation, even though the ship may be carrying containers. It is stressed that the Society's notations "Container Ship" and "Container Cargoes" both refer to the hull structure and neither implies approval of the container securing arrangements, a fact which occasionally causes some confusion.

The notation may, however, be assigned to any ship which carries containers for which container securing arrangements have been examined and approved. The Requirements are applicable to all types of container securing arrangements, including both cell-guides and lashed/twistlock systems.

It was thought, however, that the notation and the Requirements would be particularly valuable to the operator of semi-container and multi-purpose tonnage, who is less likely to be experienced in container securing matters. Moreover, the assignment of the special features notation in such cases would be an assurance to shippers and charterers that satisfactory arrangements are provided on board the ship. Owners may recognise an advantage in the notation appearing in the Register Book. It is recognised that the large container ship consortia have extensive experience in the stowing and securing of containers, but this has not exempted them from their share of damages and losses, nor from seeking the Society's advice.

Certain chartering arrangements require the charterer, not the Shipowner, to provide the loose container securing fittings to the ship. Thus, even where the plans of container securing arrangements have been approved, if the ship is not permanently supplied with the fittings it is not eligible for the class notation.

It can be seen from Fig. 2 that the certification procedure for assignment of the notation consists of four parts:

(i) Plan approval of the container securing arrangements.
(ii) Type approval of the fittings comprising the arrangements.
(iii) On-board survey and certification.
(iv) Periodical surveys.

Approval of the securing arrangements and type approval of securing devices are discussed in later sections of this paper, but the strands of the approval process come together on the ship with the requirement for the provision of an approved Container Securing Manual and for on-board survey of the arrangements leading to a recommendation for assignment of class. Unlike, for instance, lifting appliances, it is considered impracticable to require any form of initial or periodic on-board test of the arrangements. This does, of course, imply a greater importance to the earlier prototype and production test stages.

Subsequent periodical surveys for maintenance of the class notation follow usual procedures as part of the hull survey requirements.

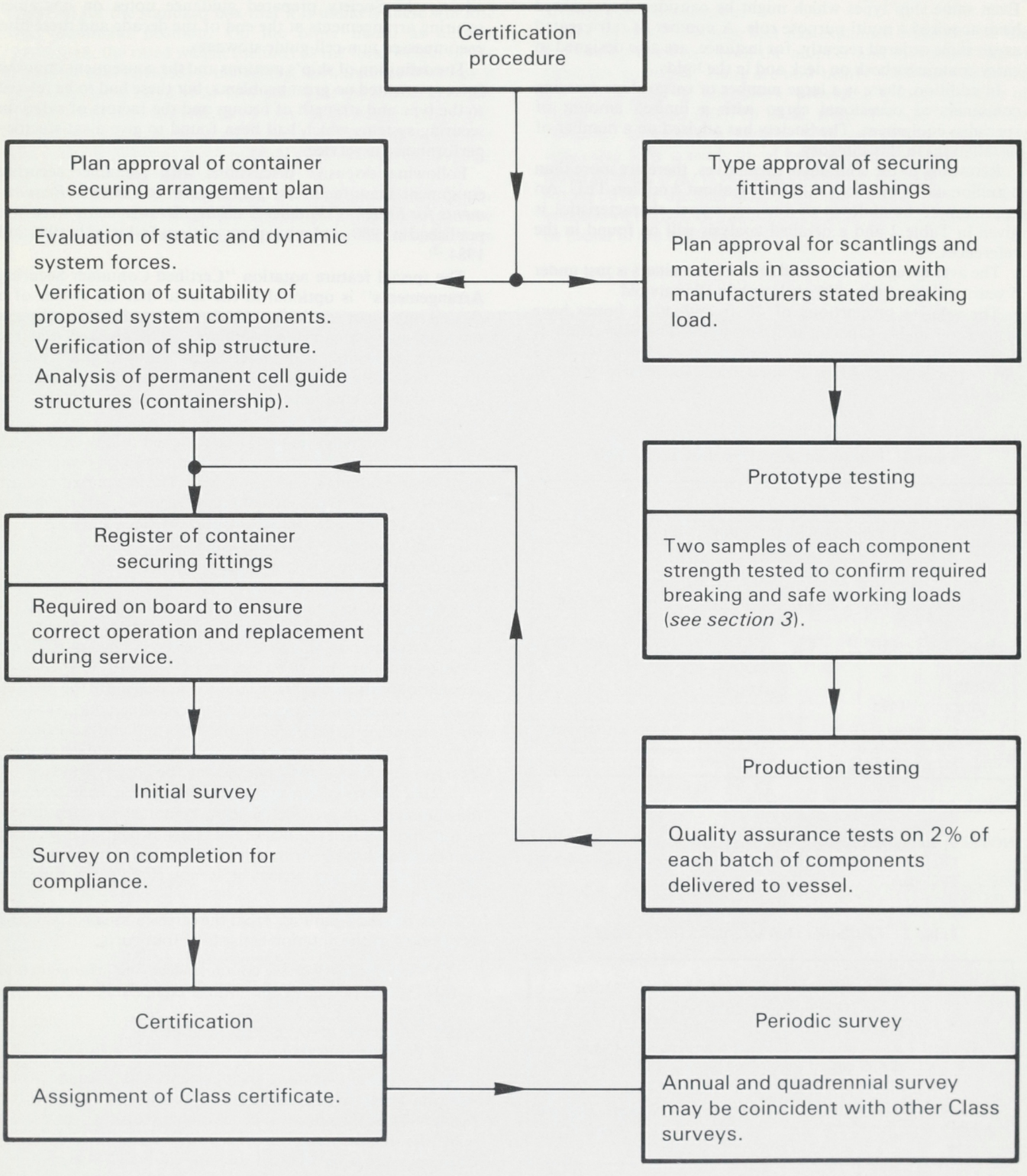


Fig. 2 Certification procedure for freight container securing arrangements

There is, at present, no intention to standardise the presentation of the Manual due to the wide variation in container stowage arrangements in ships. However, the Manual must clearly show all container stacks, together with the maximum weight of each container and location and correct application of each securing device. Additionally, every fitting type should be identified by means of a sketch and the type identification number, such as the manufacturer's model number. It is not required that devices are individually stamped with a unique identification. Certification and date of type approval of each securing device should be referenced.

Securing arrangements for over 100 cases representing more than 200 ships have been examined by the Society on behalf of owners, manufacturers and shipbuilders. In a number of cases, the Society has been asked to approve plans of a container securing system without assignment of the class notation. This has been done on a consultancy basis, both for classed and unclassed ships.

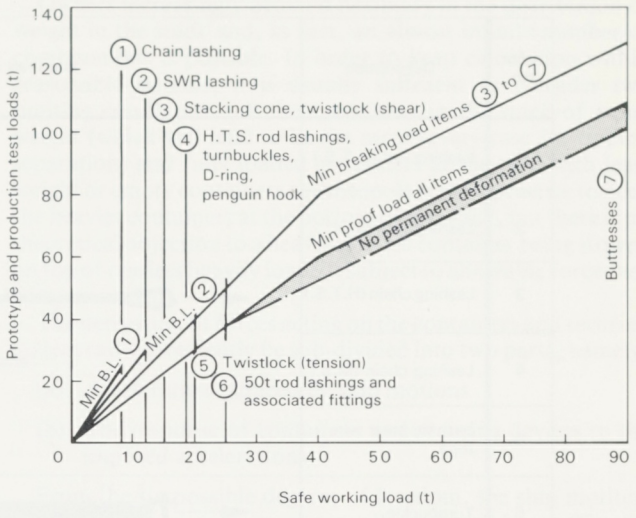


Fig. 3 Relationship between safe working load, proof load and design breaking load

3. TYPE APPROVAL OF FIXED AND LOOSE SECURING DEVICES

Type approval of securing devices is of major importance in the certification process, and is intended to demonstrate by means of mechanical testing[3] that the design and strength of the device is suitable for the intended purpose. Examination of the material specification ensures suitability for use in the marine environment. It is considered to be in the interests of manufacturers to obtain type approval for their range of securing devices at an early stage. Once type approved, the supply of a fitting is subject only to batch-type production testing which could form part of an approved quality assurance process.

It will be appreciated that standardisation is the essence of containerisation. Dimensionally, fittings must be interchangeable; not only one manufacturer's fittings, but also between manufacturers. This is principally a matter for the manufacturers and interchangeability is, generally, achievable except in the case of certain specialised types. On the other hand, standardisation of strength is considered to fall within the Society's field of interest. In type approval, therefore, two aspects of the strength of securing devices must be addresed:

(a) that the strength is adequate to restrain the containers against the forces induced by ship motions, and

(b) that the strength is compatible with the capability of the containers and preferably standardised to ensure ready replacement and also interchangeability between ships.

Unfortunately, there is no agreement on the desirable factor of safety for fittings; even the classification societies all have different requirements. However, Fig. 3 indicates the relationship between safe working loads, proof loads and design breaking loads which has been adopted by the Society to ensure an adequate margin of safety for shipboard operation and compatibility with container strength. Fig. 4 contains a transposition of Fig. 3 in respect to a range of the most commonly used fixed and loose devices.

In both figures, the recommended minimum safe working loads suitable for shipboard use are indicated.

What is to be avoided is the fitting with slightly less strength as there would be a danger of it being over-loaded if used in a location requiring "standard" strength. Thus, the Society is reluctant to type approve a lashing rod for, say, 33 tonnes breaking load or a twistlock for 26 tonnes.

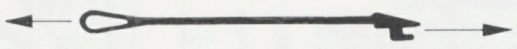
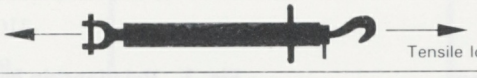
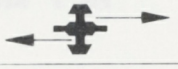
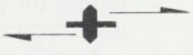
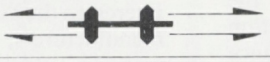
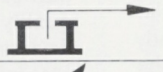
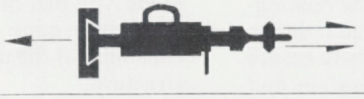
For reference purposes, a common range of fittings is illustrated and described in Appendix A. It should be noted that within the types presented there is a large number of variants, many of them standard catalogue items and others special fittings for particular purposes. The catalogues of the larger manufacturers list several hundred different items.

As with many other components, the Society confines its interest to the materials and scantlings, leaving the design to the manufacturers, most of whom are specialists in container securing, vehicle and general cargo securing systems. A list of the manufacturers with whom the Society has dealt is also given in the Appendix. It is not practicable to list here all their approved fittings (which are continually supplemented).

In line with the Society's type approval philosophy, no particular requirement is imposed regarding the material quality employed for the manufacture of "loose" securing devices. The material should, however, comply with a suitable recognised standard, which is acceptable for marine applications. Materials which are typically employed are steel, including cast steel, or ductile cast iron. Lashing rods are generally made of a high strength alloy steel. Aluminium has been proposed and is acceptable provided the alloy is resistant to metallic corrosion. Plastics have been considered, but the materials have insufficient rigidity at present for this application.

In the case of "fixed" devices which are intended to be welded into the ship's structure, then adequate precautions are required in order to ensure compatibility of material tensile strength and grade with that of the surrrounding ship structure. In general, this will require the tensile strength and notch toughness capability of the material to be equivalent to that of the parent structure.

It is well known that containerships and other types carrying containers have, for many years, operated in areas subject to seasonal ice infestation such as the approaches to the St. Lawrence River or the Baltic Sea. In such cases, it is reasonable to assume that the container securing devices have been frequently exposed to operation in low ambient air temperature conditions. The Society, however, has had no evidence of brittle failure of devices in these conditions and no requirement for material toughness at low temperature appears in the Requirements. Should it be intended that a ship operates for extended periods in areas subject to low ambient air temperature such as the Arctic or Antarctic regions, the material of exposed devices may require to be considered with regard to notch toughness in association with the design ambient temperature.

Item No.	Description	Required test modes	Recommended minima, in tonnes		
			SWL	Proof load	Breaking load
1	Lashing rod (H.T.S.)	 Tensile load	18	27	36
2	Lashing rod (M.S)		18	27	54
3	Lashing chain (H.T.S.)		8	—	20
4	Lashing chain (M.S.)		10	—	30
5	Lashing steel wire rope		12	—	36
6	Turnbuckle	 Tensile load	18	27	36
7	Twistlock (single)	 Shear load	15	22,5	30
		 Tensile load	20	30	40
8	Twistlocks (linked)	 As for item 7 + Tensile load	5	7,5	10
9	Stacker (single)	 Shear load	15	22,5	30
10	Stacker (double)	 As for item 9 + Tensile load	5	7,5	10
11	Flush socket	 Pull out load	20	30	40
12	Pedestal socket	 Pull-out load	20	30	40
		 Tangential load	15	22,5	30
13	'D' ring	 45° Tensile load	18	27	36
14	Lashing plate	 45° Tensile load	18	27	36
15	Penguin hook	 Tangential load	18	27	36
16	Bridge fitting	 Tensile load	5	7,5	10
17	Buttress	 Tensile load	*See* Note 5		

NOTES :

1. For items 6, 13, 14 and 15 where specially designed for use with chain or S.W.R. lashings a lesser SWL may be considered.
2. For items 8, 10 and 16 the recommended minimum loads quoted in the Table refer to the fittings when employed in a location in container stacks which do not transfer load to an adjacent stack. Where items 8, 10 and 16 are fitted in line with a buttress/shore support at stowage sides then test loads are to be determined in association with Note 5.
3. For items 11 and 12, where multiple flush sockets or pedestal sockets are involved test loads are to be applied simultaneously to each socket opening which can be loaded simultaneously in service.
4. For item 14, where multiple lashing points are fitted in one deck plate fitting, testing should be similarly arranged as for Note 3.
5. For item 17, test loads for buttress fittings are to be determined by detailed consideration of the individual stowage arrangement proposed.
6. Where special containers are used consideration will be given to the required minimum loads.
7. Illustrations of test modes are diagrammatic only.

Fig. 4 Test modes for fittings

4. CALCULATION METHODS AND FORCES IN THE STACK

Inevitably, much of the early work on the definition and analysis of forces in container stacks was carried out in the U.S.A. In 1969, Cushing[4] considered the static and dynamic acceleration resulting from ship motion and the consequent forces acting on stacks of deck-stowed containers.

The stowage of containers on deck using fixed and loose fittings, including lashings, was also the subject of an extensive study carried out by the J. J. Henry Co. Inc. for the U.S. Maritime Administration.[5] The study examined in detail the ship motions and phase relationships which needed to be taken into account in the determination of forces acting on the container stacks.

Subsequent work has built on these investigations and has traced the development of on-deck securing system design,[6, 7] and of the approach of particular companies to the practical development of securing systems for ships.[8, 9] Cushing has recently published a new study[10] including methods of calculation of forces in a container stack. A comparison of the two Cushing studies indicates clearly the considerable developments in the intervening 14 years.

The International Cargo Handling Co-ordinating Association (ICHCA) published a comprehensive survey of the state-of-the-art in 1981.[12] This is a valuable analysis not only of the alternative methods of securing containers from the technical and economic viewpoints, but also of operational aspects of the fittings used.

Some comparisons of the requirements of the various classification societies have been made,[13, 14] but the differences in assumptions and calculation methods should be borne in mind before drawing any general conclusions from these.

The stowage of cargo in the container is outside the scope of the Society's requirements or control. There are a number of published codes and standards on the subject, and the Society has to presume (as in other similar circumstances) that proper procedures have been adhered to.

The Society's Requirements are written on the assumption that the containers comply with the standards of strength given in the published ISO Standards,[1] and embodied in the IMO Convention for Safe Containers.[2]

It may possibly be true that the newer containers are stronger than those manufactured several years ago, both on account of improved methods of construction and because wear and tear have not yet taken their toll. However, one cannot rely upon a "strong" container being offered for stowage in a particular slot and for calculation purposes the minimum agreed standards of strength must be adopted. One might add that, apart from recent moves to introduce containers tested, certified and marked to higher strength standards (in which case, of course, higher allowable loads are implicit), there is no reason to believe that increased strength of containers is consistently achieved.

It is usual modern practice not to link adjacent stacks of weather deck and hatch stows, thus simplifying loading and discharging operations. The calculations are, therefore, made on this basis. In fact, the force distribution in, and response of, adjacent stacks is effectively the same and there would, in general, be negligible load transferred through linkages if they were fitted.

Wherever possible, examination of the container stowage arrangement is based on fully loaded containers. On-deck stacks are, however, commonly limited to about 45 tonnes/stack for 20 ft containers or 60 tonnes/stack for 40 ft containers. Further limitations may be imposed by hatch cover strength, ship stability or other factors. In such cases, the proposed stack weights are used in the calculations and these are to be clearly indicated on the operating information carried on board the ship, and in the ship's Trim and Stability/Loading Manual.

Owners increasingly demand flexibility in the distribution of weight in the stack and, in fact, an almost infinite number of combinations is possible. In order to keep calculation within reasonable bounds, it is usually sufficient to consider two limiting conditions—all the containers in the stack of equal weight (which will tend to be the most severe case for tipping separation) and fully loaded containers at the base with least weight or empty containers at the top. It is good practice to keep the heavier containers at the bottom of the stack, but there is no theoretical objection to a heavily loaded container being stowed on top of one less heavily loaded (subject to allowable forces not being exceeded).

The derivation of forces acting on the containers and securing system can conveniently be sub-divided into two parts, namely:

(a) Acceleration induced by ship motions

(b) The response of containers and securing devices to the imposed accelerations.

From the six possible degrees of freedom, the ship motions which are taken into account are roll, pitch and heave (Fig. 5). It is considered that the effects of sway, yaw and surge are adequately allowed for within the calculation procedure. It should be noted, however, that surge is important for road and rail transportation and containers are designed with this in mind.

The motion of a ship in irregular seas will itself be irregular and in the absence of reliable response data, will be impossible to predict in a specific case. However, within the maximum amplitude values taken from published data, regular cyclic response is considered an acceptable basis for the derivation of

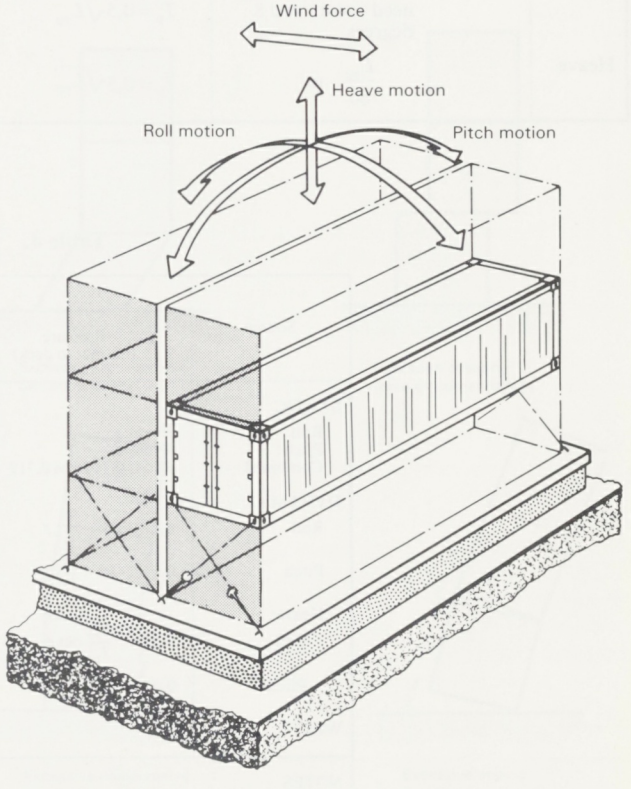


Fig. 5 Motions and wind force assumptions—typical cross-lashed stowage

accelerations, *see* Table 3. Rolling motion is dominant in the calculation of container forces and it will be noted that the maximum amplitude specified, 30 degrees, is typically 5 to 7 degrees greater than that obtained from the roll amplitude formula $\left(14{,}8+3{,}7\,\frac{L}{B}\right)e^{-0{,}0023L}$ used by the Society in other contexts. Experience at sea has, however, confirmed that extreme amplitudes are encountered and acceptance of values which are significantly less than 30 degrees would require careful consideration.

The period of cyclic motion is derived from the period of natural motion of a body in a fluid, that is

$$T=\frac{2\pi k}{\sqrt{gGM}}\text{ secs.}$$

Values of k of 0,35B for roll and 0,25L for pitch have been adopted, whilst GM_L has been taken equal to L. The periods of motions, therefore, become:

$$\text{Roll } T_r=\frac{0{,}7B}{\sqrt{GM_T}}\text{ secs.}$$

$$\text{Pitch } T_p=0{,}5\sqrt{L}\text{ secs.}$$

It is frequently difficult to obtain a satisfactory estimate of GM for the container load condition at an early stage in the design and, in the absence of better information, it is necessary to make an estimate based on past experience. In general, a value of GM_T should be selected so that the period of roll is around 12 to 16 seconds. A more convenient approach which has been proposed is to adopt the relationship

$$GM_T=0{,}06B\text{, which leads to}$$

$$T_r=2{,}86\sqrt{B}\text{ seconds.}$$

It is probably appropriate at this point to mention the definition of centre of motion. This creates some difficulty, since it is not a fixed point but traces a locus during the cycle of motion. Fortunately, however, the influence of small changes in the assumed position is relatively small and it is sufficient to define a fixed centre of motion. This is taken to be the same for roll and pitch and is:

(i) On the centreline of the ship.
(ii) At the longitudinal centre of flotation.
(iii) At the waterline in the container load condition or at one half the moulded depth, whichever is the greater.

It is convenient for calculation purposes to resolve the forces acting on a container into components acting parallel to and normal to the vertical axis of the container stack. Gravity acts vertically downwards and, therefore, when the stack is inclined at maximum roll or pitch, there are components of static weight acting both parallel to and normal to the vertical axis of the stack. The dynamic components of force are vector forces which are combined algebraically with the static components taking due account of their direction of action. The derivation of these components is shown in Appendix B, and the complete set of components is listed in Table 4.

Wind is taken to act athwartship only and to affect both exposed rows in a stack of containers. That is, wind on the "suction" side is taken to be the same as on the "pressure" side. The magnitude of wind force for a wind speed of 40 m/sec. is 1,8 tonnes on the side of a 20 ft box and 3,6 tonnes on a 40 ft box. The vertical component of wind on the top of the uppermost inclined container is neglected.

The assessment of the effect of heavy weather on exposed container stacks is necessarily empirical. The general principle is that securings in the forward 0,25L are to be suitable for forces increased by 20% above the values calculated from the Requirements except where a breakwater or similar substantial protection is fitted. The strength of securing system (i.e., the

Table 3. Ship Motions

Motion	Maximum single amplitude	Period, in seconds
Roll	$\phi = 30$ degrees	$T_r=\frac{0{,}7B}{\sqrt{GM}}$
Pitch	$\psi=12e^{-0{,}0033L_{pp}}$ but need not exceed 8 degrees	$T_p=0{,}5\sqrt{L_{pp}}$
Heave	$\frac{L_{pp}}{80}$ m	$T_h=0{,}5\sqrt{L_{pp}}$

Table 4. Components of force

Source	Component of force, in tonnes		
	Pressure (normal to deck)	Sliding (parallel to deck)	
		transverse	longitudinal
STATIC			
Roll	$W\cos\phi$	$W\sin\phi$	
Pitch	$W\cos\psi$		$W\sin\psi$
Combined	$W\cos 0{,}71\phi\cos 0{,}71\psi$	$W\sin 0{,}71\phi$	$W\sin 0{,}71\psi$
DYNAMIC			
Roll	$0{,}07024W\ \frac{\phi}{T_r^2}y$	$0{,}07024W\ \frac{\phi}{T_r^2}z_r$	
Pitch	$-0{,}07024W\ \frac{\psi}{T_p^2}x$		$0{,}07024W\ \frac{\psi}{T_p^2}z_p$
Heave:			
Roll	$0{,}05W\ \frac{L_{pp}}{T_h^2}\cos\phi$	$0{,}05W\ \frac{L_{pp}}{T_h^2}\sin\phi$	
Pitch	$0{,}05W\ \frac{L_{pp}}{T_h^2}\cos\psi$		$0{,}05W\ \frac{L_{pp}}{T_h^2}\sin\psi$
WIND		$8{,}25AV^2\cos\phi\times10^{-5}$	

NOTES
1. For definition of terms, *see text*.
2. The appropriate sign is to be used in calculating vector components of forces.
3. Wind is to be taken as acting on the exposed, outboard, stacks of containers only. Inboard stacks may be assumed protected.

containers themselves, twistlocks, lashings etc.), is required to be adequate for these nominal increased forces. It is neither practicable nor intended that specially strengthened containers or fittings should be used in the exposed forward area.

Three combinations of the individual components of motion are used in the calculations. These are:

(a) Rolling Condition:
Roll and heave acting together.

(b) Pitching Condition:
Pitch and heave acting together.

(c) Combined Condition:
Roll and pitch acting together. In this condition, it is assumed that the roll angle and the pitch angle are each 0,71 times the calculated maximum angle of roll and pitch respectively.

These are all, of course, empirical conditions, but experience has indicated that they provide a sufficient basis for approval of container securing systems.

Within each of the three conditions, it is necessary to define the instantaneous positions in the cycle of motion at which the calculations will be made. There are four limiting positions within each cycle which, for the rolling condition, are:

(a)	Bottom of roll	bottom of heave
(b)	Top of roll	bottom of heave
(c)	Bottom of roll	top of heave
(d)	Top of roll	top of heave

It can be shown that maximum racking and compression forces will arise in case (a). Minimum compression (or maximum separation) forces will arise in one of the other conditions, generally case (d). It is acknowledged that, under certain circumstances, a maximum or minumum force may arise at some other point in the cycle. However, the magnitude of the force is little greater than that from the cases used for calculation purposes and the situation may be accepted within the factors of safety applied to the system.

It will be noted that, since the calculations are made for the limiting amplitudes in the cycle of motion, the radial acceleration (centripetal force) is zero and does not enter into the calculation. The tangential component of motion is, of course, at its maximum at these points.

The instantaneous positions in the cycle of motion which are used for the calculations are, therefore:

(a) Rolling Condition.

(i) Maximum roll (descending) with maximum heave (descending).
(ii) Maximum roll (ascending) with maximum heave (ascending).

(b) Pitching Condition.

(i) Maximum pitch (descending) with maximum heave (descending).
(ii) Maximum pitch (ascending) with maximum heave (ascending).

(c) Combined Condition.

(i) 0,71 Maximum roll (descending) with 0,71 maximum pitch (descending).
(ii) 0,71 Maximum roll (ascending) with 0,71 maximum pitch (ascending).

The acceleration factors and components of force for a particular container are also dependent upon the location of the particular container. The details of the calculation of the pressure and sliding forces for a particular container in each of the three combinations of motion which are examined are given in Appendix B.

Discussion of the distribution of forces in the container stack starts from consideration of an unlashed stack, that is a stack in which each container is supported by the container below through stacking cones (providing transverse restraint only) or twistlocks (providing vertical and transverse restraint). External supports such as buttresses and lashings are not fitted. In this arrangement, all loads and forces are transmitted through the skeleton framework of the container, from container to container through the corner castings and ultimately to the ship structure.

Transverse and vertical forces are assumed to be equally divided between the two ends of the container and longitudinal forces between the two sides. It is further assumed that the two ends (or sides) of the container do not interact. This is an important assumption as it means that securing arrangements such as lashings at one end of the container make no contribution to the securing of the other end. The two ends may be considered separately.

The Society's calculation methods assumed that the component of transverse or longitudinal force parallel to the deck (sliding force) is distributed one-third to the top frame of the container and two-thirds to the bottom frame. This assumption reflects more realistically the weight distribution and securing of cargo in the container than the alternative half and half distribution. Wind force, however, is distributed uniformly over the container wall and is, therefore, taken half to the top frame and half to the bottom.

The vertical force, P, is divided equally between the four corner posts of the container, that is P/4 per corner. The sliding force H (or J) is divided equally between the two ends (sides) of the container, that is H/6 (J/6) at the top and H/3 (J/3) at the bottom of the container.

The possible modes of failure in the stack, subjected to this force system, are:

(i) Racking on the container.
(ii) Shearing in the fittings between containers.
(iii) Compression in the container corner post.
(iv) Separation (pull-out) at the container corners.

These are illustrated in Fig. 6.

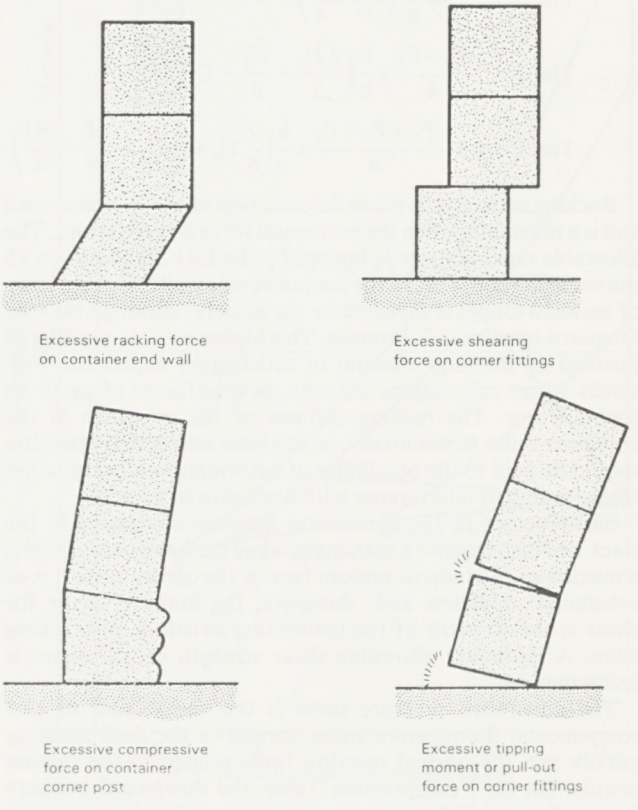


Fig. 6 Anticipated modes of failure of a container stack

It now becomes possible to consider the forces in the whole container stack. For the purpose of illustration, a three-tier stack in the rolling condition will be considered.

In order to quantify the forces, the following symbols are used:

Container height	h metres
Container breadth	b metres
Sliding force (transverse)	$H_3\ H_2\ H_1$ tonnes
Vertical force	$P_3\ P_2\ P_1$ tonnes
Wind force (per container)	Q tonnes

The forces in the stack are given by:

(a) Racking force per end wall:

Tier 3 $\dfrac{H_3}{6}+Q/4$

Tier 2 $\frac{1}{2}\left(H_3+\dfrac{H_2}{3}\right)+\dfrac{3Q}{4}$

Tier 1 $\frac{1}{2}\left(H_3+H_2+\dfrac{H_1}{3}\right)+\dfrac{5Q}{4}$

(b) Shear force per bottom corner:

Tier 3 $1{,}1\left(\dfrac{H_3}{4}+\dfrac{Q}{4}\right)$

Tier 2 $1{,}1\left(\dfrac{H_3}{4}+\dfrac{H_2}{4}+\dfrac{Q}{2}\right)$

Tier 1 $1{,}1\left(\dfrac{H_3}{4}+\dfrac{H_2}{4}+\dfrac{H_1}{4}+\dfrac{3Q}{2}\right)$

Note that the factor 1,1 is used to relate the maximum shear stress to the mean shear stress in the connecting fitting between containers.

(c) Downward pressure force, per corner:

Tier 3/2 $\dfrac{P_3}{4}\pm\dfrac{h}{b}\left(\dfrac{H_3}{6}+\dfrac{Q}{4}\right)$

Tier 2/1 $\dfrac{P_3+P_2}{4}\pm\dfrac{h}{b}\left(\dfrac{2\,H_3}{3}+\dfrac{H_2}{6}+Q\right)$

Tier 1/base $\dfrac{P_3+P_2+P_1}{4}\pm\dfrac{h}{b}\left(\dfrac{7}{6}H_3+\dfrac{2}{3}H_2+\dfrac{H_1}{6}+\dfrac{9Q}{4}\right)$

Racking occurs as in-plane deformation of the container wall and is a maximum when the horizontal force is a maximum. The allowable racking force is limited by the ISO Standards to 15 tonnes in the end wall. In the container side wall a racking force of up to 10 tonnes is accepted by the Society, although the ISO Standard remains at 7,5 tonnes. This higher value is considered justified by the large amount of satisfactory experience with stacks where calculations indicate racking forces of up to 10 tonnes occur. The racking stiffness of the two ends of the container differ substantially, as has been noted, and attention should be paid to the possibility of deformation of a container stack leading to interference with fixed ship structure.

Shear occurs in the connection between containers in the stack and also reaches a maximum when the horizontal force is a maximum. The top or bottom face of the corner casting is of substantial thickness and, therefore, the limiting factor for shear is the strength of the connecting twistlock or stacking cone. A minimum allowable shear strength of 15 tonnes is recommended.

The downward pressure force is the vector sum of two components; the pressure force normal to the deck resisting gravity and the normal reaction force related to the tipping couple. On the "compression" side, the downward pressure force is the sum of these two components and is at its maximum when they are both at their maxima. A limitation is imposed, however, by the capability of the container below to withstand compression in its corner posts. The limit is 2,25 × the rated weight of container, that is 45 tonnes for a 20 ft container and 67,5 tonnes for 40 ft containers. This is not usually a significant factor for on-deck stacks, but becomes more important where five or more tiers are stowed in holds.

On the "tension" side, the resultant force is the difference of the two components and may be positive or negative. Where negative, separation (tipping) will occur, and in order to prevent this twist-locks or other means of restraint are required. The allowable pull out force on the horizontal face of the container corner casting is 20 tonnes at the bottom of the container and 15 tonnes at the top. The safe working load of the twistlock must be at least as great as this, but no advantage can be gained from fitting a twistlock of greater strength.

The possibility exists that the minimum pressure force will, in fact, arise as the difference between the two component minima, that is at the top of the motions. This occurs chiefly in the combined condition and it is always prudent to make the calculation for this point in the cycle of motion in all conditions.

In order to consider the forces in the stack and the way these vary with changes in certain parameters, it is helpful to use a specific example. A conventional bulk carrier of main dimensions 180 × 28 × 16 metres is typical of many recent cases. A large number of calculations have been made using this example, and these form the basis of the analysis in this section. By way of illustration, the DTC output for an on-deck and an in-hold stack are shown in Appendix C.

The principal component of transverse force is that due to the static weight of the container, namely 0,5W for a 30 degree roll. At the same time, the transverse component of the heave factor is 0,1W, resulting in a total of 0,6W acting transversely and independent of the period of rolling of the vesssel. The period of roll is generally in the range 10 to 20 seconds, corresponding to GM values between 4 and 1 metres, and so far as information is available, the estimated GM_T for the actual container load conditions is used in the calculations. The racking and separation forces for a 3 × 15 tonnes stack without wind, on the hatch of the example ship, are shown in Fig. 7. Both forces are

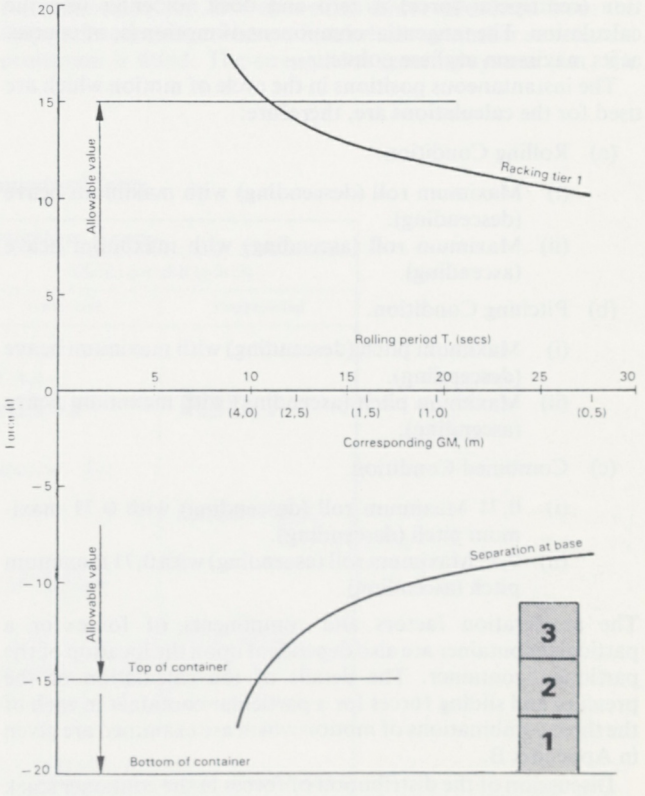


Fig. 7 Influence of rolling period on stack forces

within allowable limits but become larger at an increasing rate as the period decreases until the allowable racking limit is reached at a period of about 11 seconds.

Referring to the equations in Appendix B, it will be seen that the components of force are all linearly related to the appropriate dimensions x, y or z from the centre of motion. It follows that the forces in the stack are similarly dependent upon the location of the stack in the ship. Fig. 8 shows certain forces for a stack of 3×18 tonnes located at the centre of motion, and also the change in the forces as the stack is moved forward and athwartship. Fig. 9 shows the same stack at the centre of motion as the vertical position is changed.

Consider first the rolling condition. Racking is dependent on z_m and increases as the stack is raised, but is constant over the length and breadth of the ship. The compression/separation force is constant over the length but alters as the y-dependent component of pressure and the z-dependent reaction couple to the sliding force alter in the athwartship and vertical axes respectively.

The Pitching condition would show a similar pattern, reversing the effect of x and y.

The Combined condition combines the effect of rolling and pitching, but the effect of the 0,71 factor is to reduce the absolute level of the forces.

Two conclusions can be drawn from the figures; firstly that the athwartship position of the stack has relatively little influence on the forces, but that vertical location is more significant. The value of z_m is dependent both on the vertical location of the stack and on the definition of the vertical position of the centre of motion which is, therefore, important. The second conclusion is that compression or separation force in the combined condition increases rapidly towards the end of the ship. Whether this or the rolling condition forces is the greater depends on the exact combination of factors, but clearly it is not sufficient to look at the rolling condition only.

The effect of wind on the forces in the stack is considerable, and it is commonly necessary to restrict the weight of the uppermost tier of the exposed outer stacks on deck and hatches. Although three tier stacks of acceptable weight can usually be arranged, certainly of 20 ft containers, difficulty often arises with proposals to carry four tiers. The point is illustrated in Fig. 10, which shows the separation force at the base of a four tier

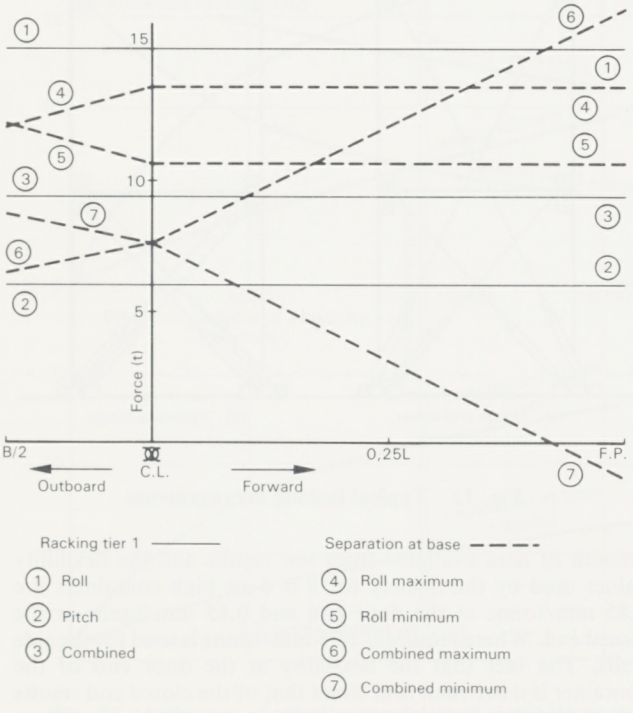


Fig. 8 Stack forces related to longitudinal location

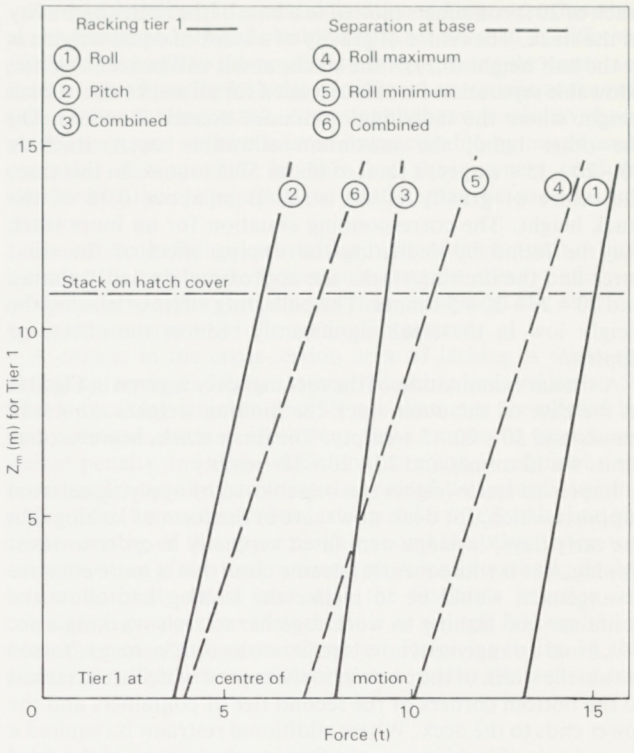


Fig. 9 Stack forces related to vertical location

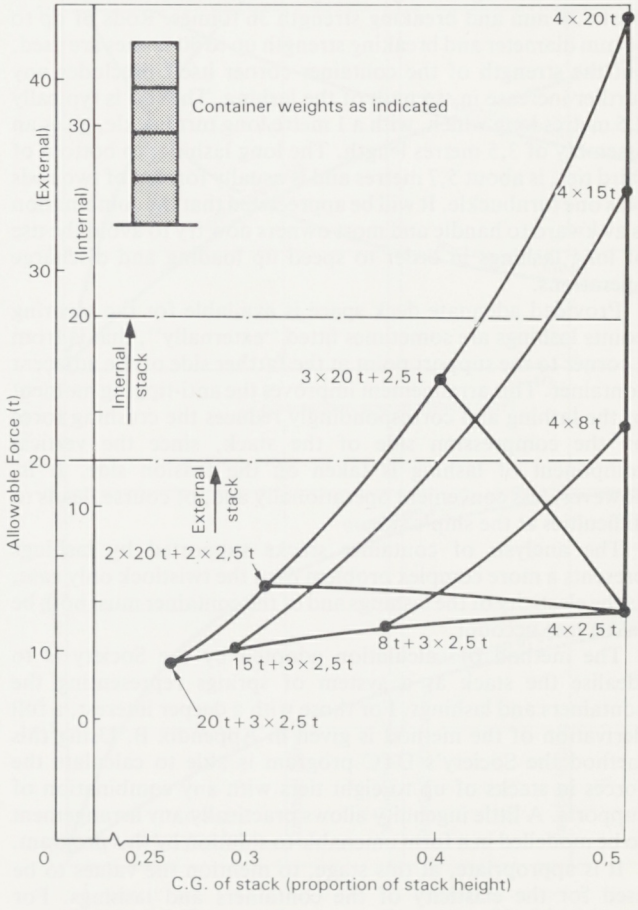


Fig. 10 Separation force at the base of a four-tier stack

stack of 20 ft containers plotted to a base of the centre of gravity of the stack. The centre of gravity of a stack of equal weights is at the half height (0,5) of the stack, and it will be seen that the allowable separation force is exceeded for all stacks of uniform weight where the individual container exceeds 7 tonnes. On the other hand, the maximum allowable outer stack is 20 + 20 + 15 + empty, a total of about 57,5 tonnes. In this case, the centre of gravity of the stack is at about 0,36 of the stack height. The corresponding situation for an inner stack may be found by deducting the tipping effect of the wind force and the limiting stacks are approximately 4 × 10 tonnes and 20 + 20 + 20 + 5 tonnes. The ballasting effect of placing the weight low in the stack significantly reduces the effects of tipping.

A similar examination of the racking force is given in Fig. 11. In the case of the outer stack the limiting weights are 4 × 10 tonnes and 20 + 20 + 5 + empty. The inner stack, however, has limits 4 × 12 tonnes and 20 + 20 + 12 + empty.

Improved stackweights can be achieved by applying external supports which, for deck stows, are in the form of lashings. In the early days, lashings were fitted vertically in order to resist tipping, but it subsequently became clear that a more effective arrangement would be to incline the lashing and allow the container and lashing to work together to resist racking also. The usual arrangement now is to fit one level of lashings crossed within the width of the container, the tops of which are attached to the bottom corners of the second tier of containers and the lower ends to the deck. Where additional restraint is required a second pair of lashings may be fitted to the bottom of the third tier of containers, Fig. 12.

Chain and steel wire rope lashings are still used for smaller installations, but the breaking load of lashings of these types is usually not more than 20 tonnes and their use is now more common for vehicles rather than containers. The most common container lashing is a high strength alloy steel rod of diameter about 24 mm and breaking strength 36 tonnes. Rods of up to 30 mm diameter and breaking strength up to 50 tonnes are used, but the strength of the container corner itself precludes any further increase in strength of the lashing. The rod is typically 2,5 metres long which, with a 1 metre long turnbuckle, gives an assembly of 3,5 metres length. The long lashing, to bottom of third tier, is about 5,7 metres and is usually formed of two rods plus one turnbuckle. It will be appreciated that the combination is awkward to handle and most owners now try to avoid the use of long lashings in order to speed up loading and discharge operations.

Provided adequate deck space is available for the securing points lashings are sometimes fitted "externally", that is from a corner to the support point at the farther side of the adjacent container. This arrangement improves the anti-tipping moment of the lashing and correspondingly reduces the crushing force on the compression side of the stack, since the vertical component of lashing is taken on the tension side. It is, however, less convenient operationally and, of course, leads to difficulties at the ship's side.

The analysis of container stacks supported by lashings presents a more complex problem than the twistlock only case, as the elasticity of the lashings and of the container must both be taken into account.

The method of calculation adopted by the Society is to idealise the stack as a system of springs representing the containers and lashings. For those with a deeper interest, a full derivation of the method is given in Appendix B. Using this method the Society's DTC program is able to calculate the forces in stacks of up to eight tiers with any combination of supports. A little ingenuity allows practically any arrangement to be modelled in a form amenable to solution by this program.

It is appropriate, at this stage, to mention the values to be used for the elasticity of the containers and lashings. For containers, the values of flexibility (the inverse of stiffness) are derived from the ISO test requirements. There is a substantial

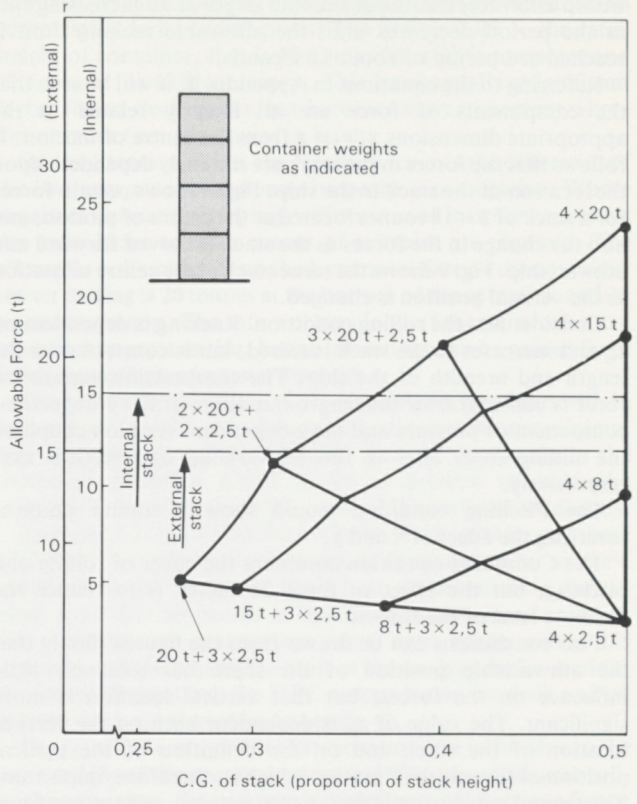


Fig. 11 Racking force in tier 1 of a four-tier stack

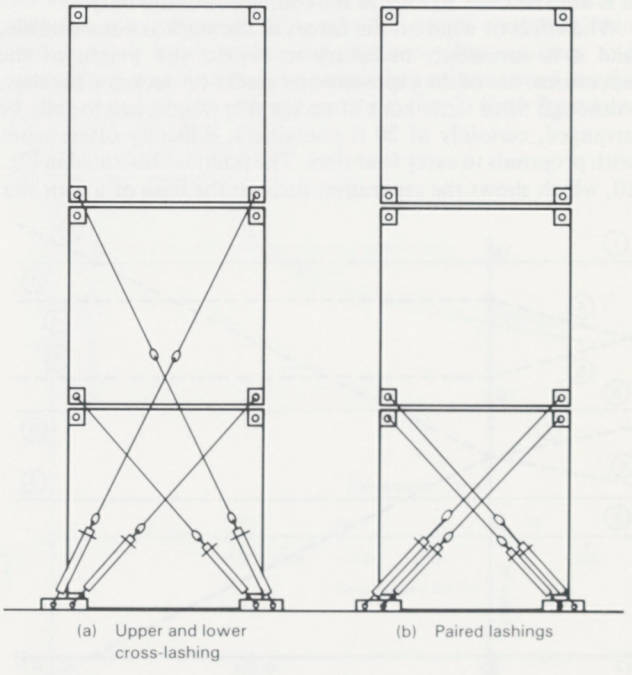


Fig. 12 Typical lashing arrangements

amount of data available from test results and the flexibility values used by the Society for 8 ft 6 ins high containers are 2,85 mm/tonne at the door end and 0,65 mm/tonne at the closed end. Where required, 1,75 mm/tonne is used for the side walls. The fact that the flexibility at the door end of the container is more than four times that of the closed end results in a quite different distribution of forces between the container and its supports at the two ends. At the closed end the container

bears a significant proportion of the load and the racking strength is typically the limiting factor. At the door end, most of the load goes to the external supports and it is their strength which is likely to be the limiting factor. Some ports ensure that containers are stowed all facing the same way (generally, of course, all door ends protected from the weather). Since this is clearly the limiting arrangement, two calculations are made for a lashed stack—all door ends together and all closed ends together.

The calculations rest upon the equality of deflections at the container/lashing connection. The elongation of the lashing includes bending distortion of the end connection and the intermediate eyes and hooks as well as extension under load of the lashing, turnbuckle and end fittings. Based on available test data, average values for typical lashing assemblies have been determined and these are expressed in the Requirements in the form of an effective modulus of elasticity. For a rod lashing, the value used is 9800 kg/mm^2, less than half that of steel, which corresponds to an overall elongation at maximum working load of approximately 15 mm.

It is acknowledged that the flexibility of lashing assemblies will vary with type and with installations of the same type in different ships. Nonetheless, it is a practical necessity to adopt a nominal value and the value quoted above would appear to be supported by experience. However, the effect on the force distribution of varying the assumed modulus of elasticity of the lashing assembly is illustrated in Fig. 13, which is prepared for both ends of a three tier stack with single lashings. Racking and separation forces are both at their maximum values when the modulus of elasticity of the assembly is zero (corresponding to an unlashed stack). As the elasticity of the lashing is increased, more load is taken by the lashing and racking and separation forces in the container reduce correspondingly until the point is reached where all forces are within allowable limits. Further increase in the assumed modulus of elasticity attracts more load into the lashing which eventually reaches its allowable load limit.

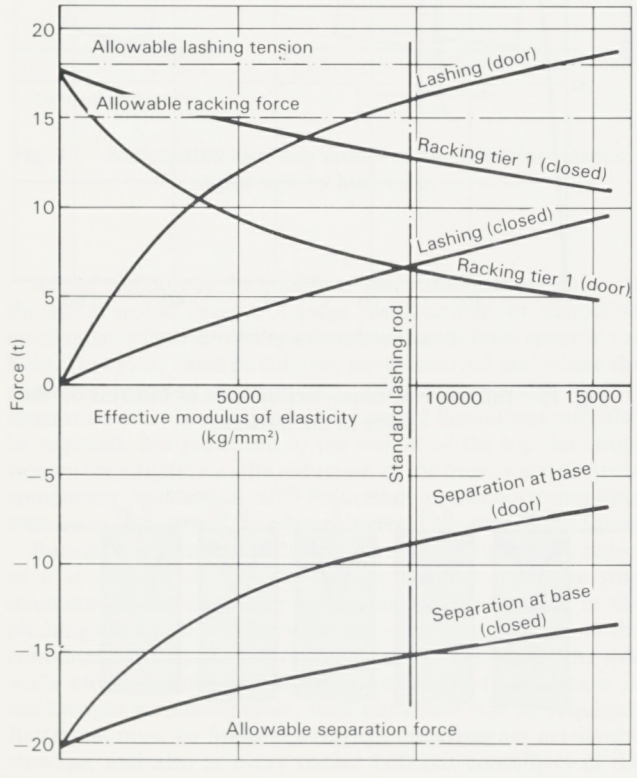


Fig. 13 Influence of effective modulus of elasticity of the lashing assembly on stack forces

As the flexibility of the container door end is greater than that at the closed end, the allowable limits are reached at different points. This leads to the possibility of optimising the container stackweights by using lashings of different elasticities at the two ends of the container stack. Although such proposals have been made, they tend to be rendered impracticable by mixed ends container stowage and by the fact that owners tend to standardise their equipment so that it may be used in any position.

Since the calculation uses the flexibility of the support, which includes the product (effective cross-section area × effective modulus of elasticity) it follows that changes in the effective cross-section area will follow a similar pattern.

A change in the cross-section area of lashing is relatively simple to arrange. Higher strength lashing rods of up to 50 tonnes breaking strength and 30 mm diameter are offered by many manufacturers. However, these impose a significant weight penalty and if the additional strength is required only occasionally, an alternative is to use paired "standard" lashing rods. In this arrangement one lashing rod is fitted to the bottom corner casting of the upper container and the other to the top corner casting of the lower container. A load equalising device is not normally fitted and it is the Society's practice for calculation purposes to treat the pair as a single lashing of 1,5 times the cross-section area of one rod. Referring to Fig. 14, the greater the effective area of lashing, the smaller the racking and

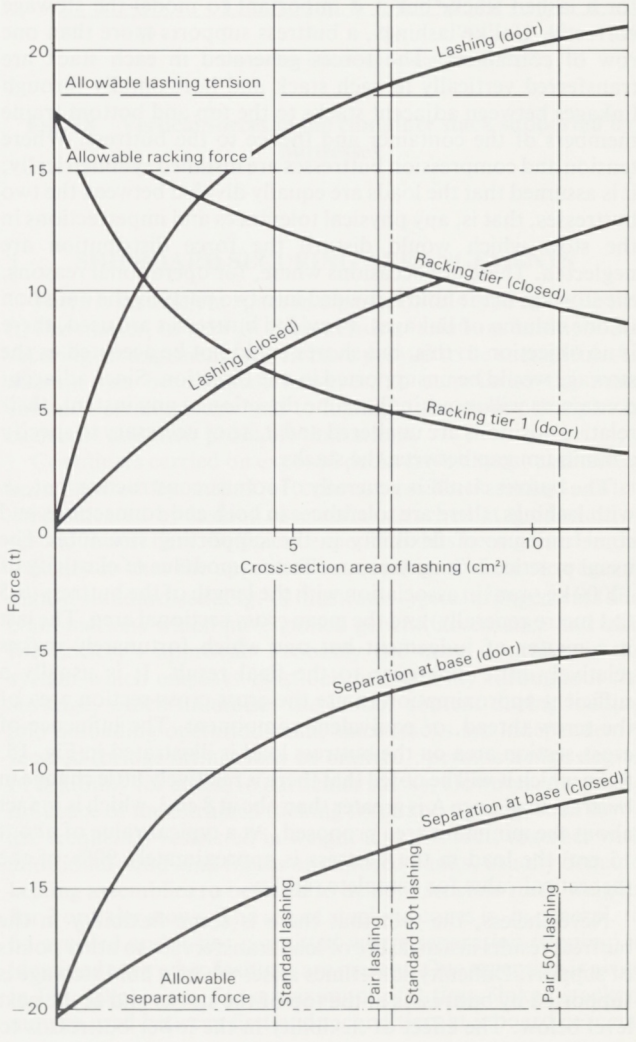


Fig. 14 Influence of cross-section area of lashing on stack forces

the tipping forces in the container. On the other hand, the allowable load on one lashing is 18 tonnes and for 1,5 lashings would, therefore, be 27 tonnes. The rate of increase of lashing load with area is less rapid than this. Consequently, the choice of 1,5 as the effectiveness factor is considered to represent a satisfactory position for approval purposes.

A further difficulty from the point of view of calculation of lashed stacks is the presence of manufacturing tolerances on the component items of the securing system and, in order to make operation reasonably easy, these tolerances are significant. The average tolerance of the twistlock shaft in a corner fitting is 7 mm and theoretically the container could slide by this amount before restraint becomes effective. In practice, it is doubtful whether anything like this amount of movement occurs and examination of corner castings, for instance, reveals little or no evidence of sliding.

A calculation method which satisfactorily accounts for the myriad combinations of tolerances in the securing system would be horrendously complicated and, therefore, impracticable for routine application. Furthermore, no satisfactory method has yet been developed, so far as is known to the authors. For practical application, it has been found that acceptable calculations can be made neglecting these tolerances and this is now the Society's practice.

The use of lashings in holds is becoming increasingly uncommon, and most underdeck stows are now supported by buttresses in association with stacking cones or twistlocks and linkages. The calculation of forces is made in the same way as for a lashed stack, but it is important to model the stowage correctly. Unlike lashings, a buttress supports more than one row of containers. The forces generated in each stack are transferred vertically in each stack and horizontally through linkages between adjacent stacks to the top and bottom frame members of the container and thence to the buttress. Where tension and compression buttresses are installed symmetrically, it is assumed that the loads are equally divided between the two buttresses, that is, any physical tolerances and imperfections in the stow which would disturb the force distribution are neglected. There are occasions where, for operational reasons, the stowage in the hold is divided into two parts by the omission of one column of linkages. Provided buttresses are used, there is no objection to this, but shores could not be accepted as the stowage would be unsupported in one direction. Since adjacent containers will move in the same direction at any instant, their relative positions are unaltered and it is not necessary to specify a minimum gap between the stacks.

The buttress itself is generally of robust construction but, as with lashings, there are tolerances in both end connections and some measure of flexibility in the supporting structure. The usual practice is to assume an effective modulus of elasticity of 12000 kg/mm^2 in association with the length of the buttress (0,5 to 1 metre generally) and the mean cross-sectional area. The last is a matter of judgement but one which fortunately makes relatively little difference to the final result. It is usually a sufficient approximation to use the gross cross-section area of the screw thread, or equivalent component. The influence of cross-section area on the buttress load is illustrated in Fig. 15, from which it will be noted that there is relatively little change in buttress load once A is greater than about 8 cm^2, which is in fact about the minimum area proposed. At a typical value of about 15 cm^2 the load in the buttress is approximately 90% of the theoretical value for complete rigidity.

Nevertheless, the fact that there is some flexibility in the buttress results in a measure of load transference to other points of support. Difficulty sometimes arises where a hold stowage is supported by buttresses at the top of the stacks and at the next level below. The effect of flexibility in the lower buttress is to transfer perhaps 10 tonnes of load directly to the upper buttress. This represents a small proportional reduction in the lower buttress load, but may almost double the required breaking load of the upper buttress and the reasons for this are not always fully appreciated. Where the buttress supports N rows of containers the contribution of each container to the total load P is P/N tonnes. One half the load from the outer container is transmitted directly to the buttress through the corner casting and, therefore, the load in the top frame of the outer container is:

$$\left(N-\tfrac{1}{2}\right)\frac{P}{N}=P\left(\frac{2N-1}{2N}\right)\text{ tonnes}$$

This is illustrated for a five row stack in Fig. 16. The maximum allowable compressive forces in the top and bottom frame members of the container are 22,5t and 35t at top and bottom respectively of a 20 ft container. Compliance with these values frequently imposes a limit on the stackweight, particularly where the buttress is fitted at the top of the stack.

Where the buttress is fitted at an intermediate level, it is considered that each container will bear its appropriate proportion of load by virtue of the relative strength of the top and bottom container frames. Therefore, the total compressive force in the frames may be compared directly with the maximum allowable, that is 57,5t for 20 ft or 84t for 40 ft containers.

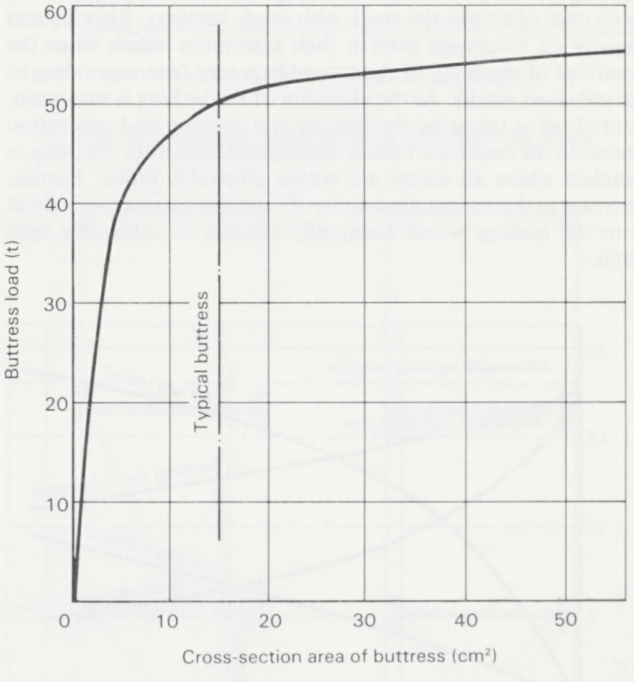


Fig. 15 Influence of cross-section area of buttress on the force in the buttress

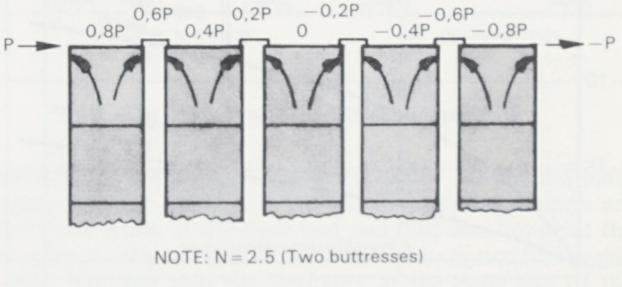


Fig. 16 Loads to linkages and container frame members in line with buttresses

By the same token, the linkages themselves are required to be sufficiently strong to transmit loads between adjacent stacks, and by analogy with the buttress/container force, the maximum force in the linkage is $P\left(\frac{N-1}{N}\right)$ tonnes. The standard bridge fitting and linkage plate are not usually sufficiently strong for this purpose and special fittings are, therefore, required in line with buttresses.

A stack supported by buttresses may be subject to one further possible collapse mechanism, namely "bursting" (Fig. 17). In relative terms, the buttress effectively fixes the stack at the point of support. Intermediate tiers rack and ultimately the point is reached where separation between containers occurs and a container tends to be ejected—just as will happen with a pile of childrens' bricks. The separation and compression forces at each interface are shown in Fig. 18 for a 3, 4, 5 and 6 tier stack. The maximum separation force usually occurs at about two-thirds of the height of the stack.

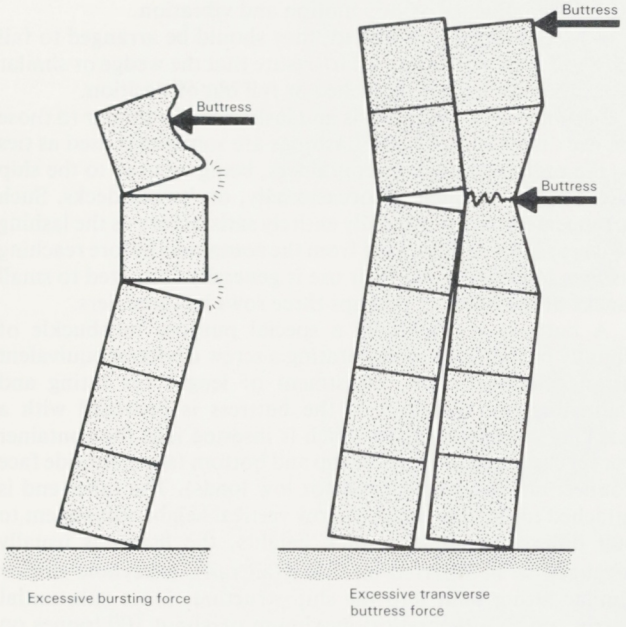


Fig. 17 Anticipated bursting modes of the container stacks supported by buttresses

Actual ejection of the container and subsequent collapse of the stack would involve a large displacement or distortion mechanism which may be restricted by the confined space in the hold. However, cases of collapse have occurred and where the potential situation is identified, adequate restraint against separation must be provided. Stackweight limitations may also be required, but reduction of the weight of the top tier could worsen the situation as the reduction of the downward pressure component may offset any reduction in the corresponding transervse component, and hence increase the separation force.

Buttresses are infrequently fitted in the longitudinal direction as it is difficult to provide suitable support from the ship structure. However, in the end holds the acceleration in the pitching condition may be such that either compression in the container corner posts (20 ft containers) or racking in the side walls (40 ft containers) becomes excessive. If reduction in stackweight is unacceptable, then buttresses will be required. Buttresses must be fitted at every container corner across the stowage, and also at every corner between containers in the longitudinal direction. The calculations, however, and the general principles of the arrangement are similar to those for the more common transverse case.

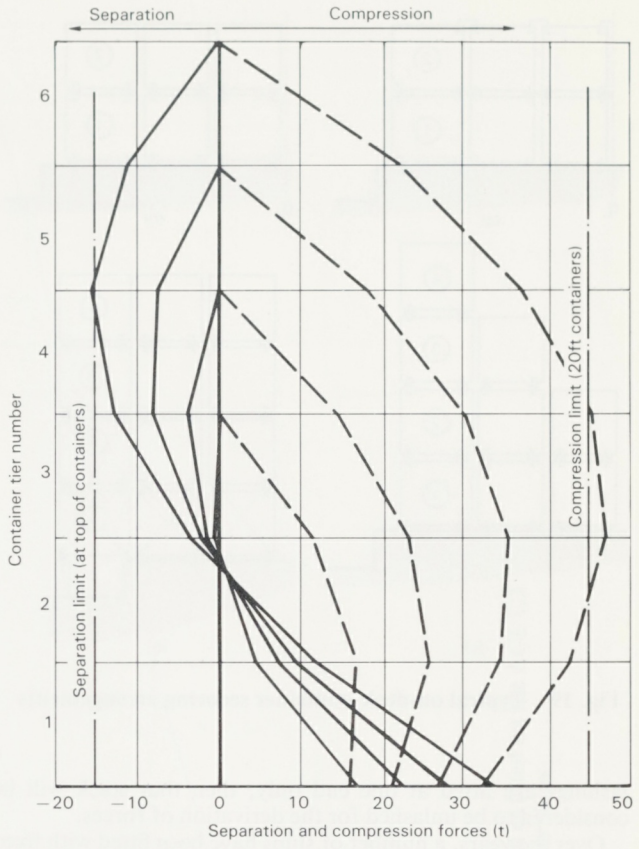


Fig. 18 Vertical forces in the container stack supported by buttresses

5. SHIPBOARD SECURING ARRANGEMENTS

There is insufficient space in a paper of this type to do justice to this matter, in view of the extensive variations in shipboard securing arrangements which have proved to be successful. An attempt has been made, however, to summarise the more common arrangements and to highlight the main principles in each case and their probable limitations.

Containers carried on exposed decks have almost exclusively been secured by means of cone or twistlock fittings, often supplemented by lashing assemblies attached at the lowest or second lowest tiers. Sufficient experience has been gained in the industry so that the approach to securing of these stowages is almost standardised. Fig. 19 illustrates typical arangements and combinations which have gained general acceptance and also the Society's approval. Probably the most desirable is the system which employs twistlock fittings only throughout the stowage, which minimises the labour content during loading and unloading operations and, since stacks are independently secured (bridge fittings may be omitted), permits a high degree of flexibility for access to particular stacks. However, due to the influence of unrestrained racking force and tipping, such stows are frequently restricted in weight and this fact, together with additional wind load forces on exposed flanks, usually demand lashing assemblies to be fitted to achieve sensible stack weights for 3 or 4 tier stows. The use of stacking cones is, in general, to be avoided and is not permitted where separation (tipping) is identified even when lashings are present. One exception is given in Fig. 19(a) where for a maximum of 2 tiers, linked stackers may be used between first and second tiers at inboard corners.

For lashed stacks on deck, consideration should be given to leaving sufficient space between the ends of adjacent stacks for the lashings to be applied at both ends of the containers. If

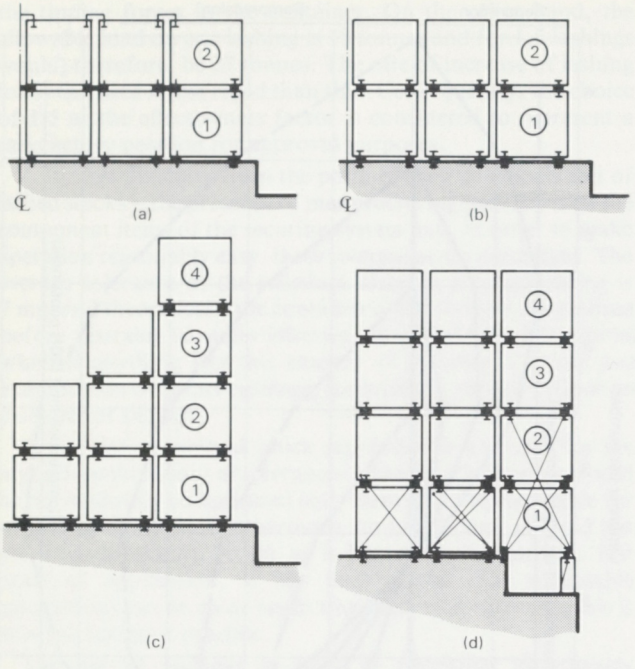


Fig. 19 Typical on-deck container securing arrangements

lashings are fitted at one end only, then that stack will be considered to be unlashed for the derivation of forces.

Over the years, a number of ships have been fitted with fixed cell-guides on exposed decks, and the most recent and comprehensive arrangement known to the authors is fitted to the ACL G3 Ro-Ro/container ships, Fig. 20. Developed by Transatlantic AB and Navire Cargo Gear of Sweden, the system was subject to comprehensive structural analysis by the Society and approved for assignment of the notation. Particular emphasis was given to avoidance of main hull bending being transmitted to the structures and to the design of cell-guide supports at connection to the upper deck. Up to 4 tiers of 40 ft containers may be carried and provision of portable mid-bay guides also permits carriage of 20 ft containers. The height of the guide bars is of importance with respect to adequate restraint of the uppermost container. In general, it is considered that the top of the guides should extend to not lower than one third the height of the uppermost container above its base in order to give reasonable security. The first ship is now in service and the objective of the system, namely to simplify and reduce port turnround operations, would, according to initial reports, appear to have been achieved.

The cellular container ship with a fixed cell-guide system to enable containers to be carried below decks is well known and generally successful and as such will not be discussed here. It is, however, of interest to mention that the support of the mid-hold end of 20 ft containers which are stowed in a 40 ft guide system presents considerable problems. A number of solutions, involving portable or semi-portable mid-bay guides, have been approved by the Society. All solutions sighted by the authors, however, involve some degree of handling and/or stowage facilities. With the development of twistlock and lashing systems, a reasonable number of containers could be carried in holds and in 'tween decks in multi-deck ships with sufficiently strong 'tween deck hatch covers. There are obvious advantages, however, in stowing containers in four or more tiers without the use of cell-guides, particularly in single deck ships such as bulk carriers which could then take on a multi-purpose role.

The use of special devices supporting the containers from the ship structure at appropriate points has enabled such stowages to be introduced in a more effective way, and arrangements of up to six rows by six tiers are now in service. A number of typical arrangements are illustrated in Fig. 21. When referring to the figure, it should be appreciated that virtually any combination of weights, tiers, stacks, fittings, and supports is feasible depending upon limitations of strength and imposed ship motion forces for the particular installation. Therefore, the figures may only be used in the most general sense to appreciate some of the types of arrangement which are acceptable.

There is no generally accepted name for the special supporting devices and, for present purposes, the following terms are used:

Lashing—A device capable of resisting tensile forces only.

Buttress—A device capable of resisting tensile or compression forces.

Shore—A device capable of resisting compression forces only.

With the development of specialised securing systems, the use of shores has declined. No matter how well fitted and tightened at the loading port, there is a tendency for them to work loose under the influence of ship motion and vibration.

Where shores are proposed, they should be arranged to fail safe and means are required to ensure that the wedge or similar device cannot become detached or fall out of position.

Lashings are used in holds and lashed stacks similar to those on deck may be arranged. Lashings are sometimes used as ties to the outboard stack of containers, being secured to the ship structure at the bilge or, occasionally, on 'tween decks. Such arrangements are not usually entirely satisfactory as the lashing relieves relatively little load from the containers before reaching its own load limit, and their use is generally restricted to small stacks of the order of perhaps three rows by three tiers.

A buttress is essentially a special purpose turnbuckle of chunky proportions incorporating a screw device or equivalent arrangement to allow adjustment of length for fitting and tightening up. One end of the buttress is provided with a stacking cone type fitting which is inserted into the container corner casting (generally the top and bottom faces, but side face connection may be accepted for low loads). The other end is attached to the ship and, to allow vertical height adjustment to suit different container stack heights, the fitting is usually arranged to be inserted into dovetail rails, a keyhole slot or similar fitting built into the ship structure. Since substantial forces, up to a theoretical maximum of about 100 tonnes on occasions are transmitted through these fittings, it is necessary to ensure that the ship structure is suitably strengthened in way.

5.1 Other Systems

One is constantly surprised at the ingenuity of the container industry in developing new ideas and improved methods. The great majority of container stowage systems are either variants of the arrangements discussed previously or they are based on the use of in-hold cell-guides. However, there are other systems which should be mentioned.

5.1.1 Line Load Systems

The essential feature of line loading is that the container weight is distributed through bearers placed below the bottom side frames of the container so that forces are not transmitted through the corner castings. Wooden planks are usually used which, due to their flexibility and "crushability" are preferable to steel battens. The object of the system is to distribute the loading from the containers thus avoiding substantial point loads. It is used particularly for hatch covers whose local strength would not otherwise be suitable to support the stowage of containers.

The load in a container is transmitted principally through the floor to the bottom frames and thence, to the corner casting. The ISO test for floor strength (lifting the container when loaded to twice its rated weight) in fact places a vertical shear

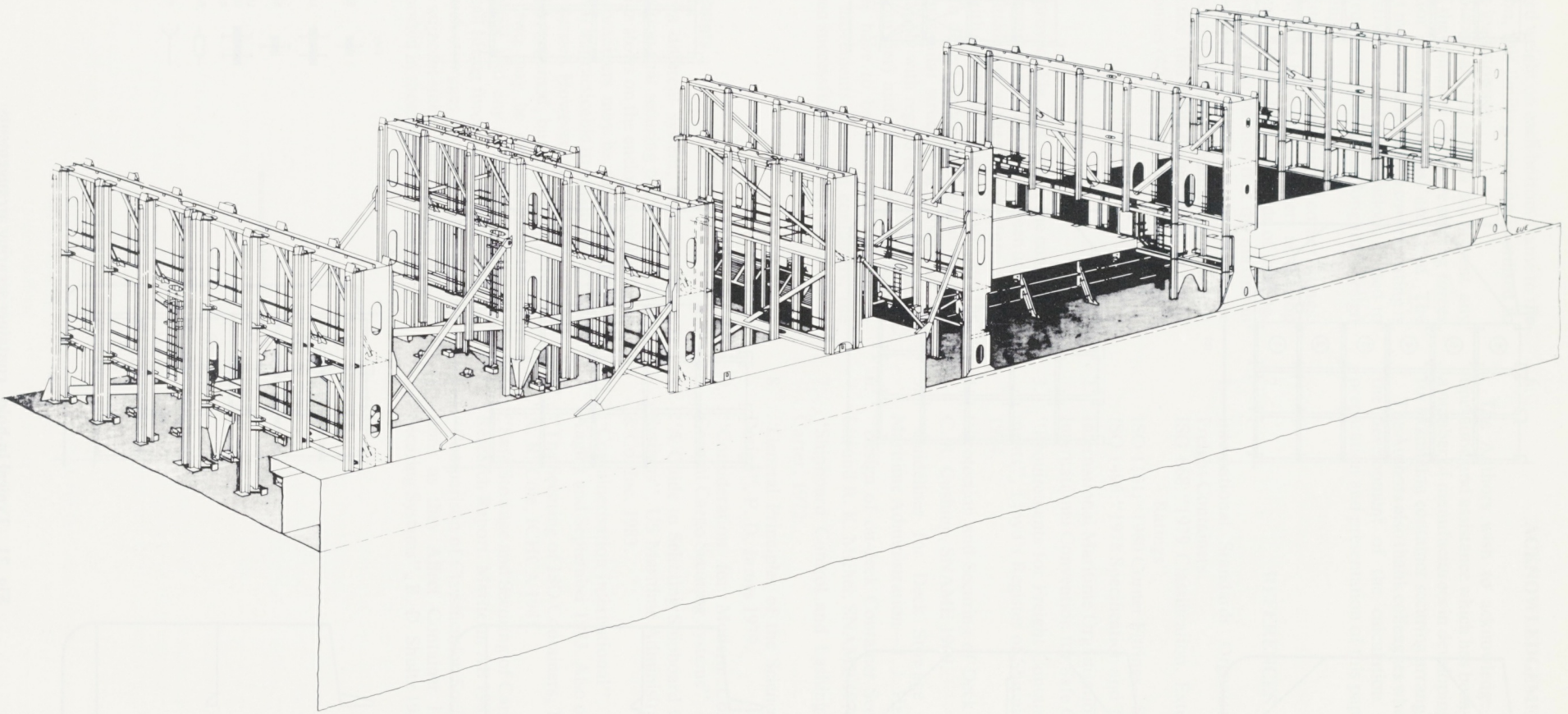


Fig. 20 On deck cell guide system as fitted on the ACL G3 Ro-Ro/Container ships

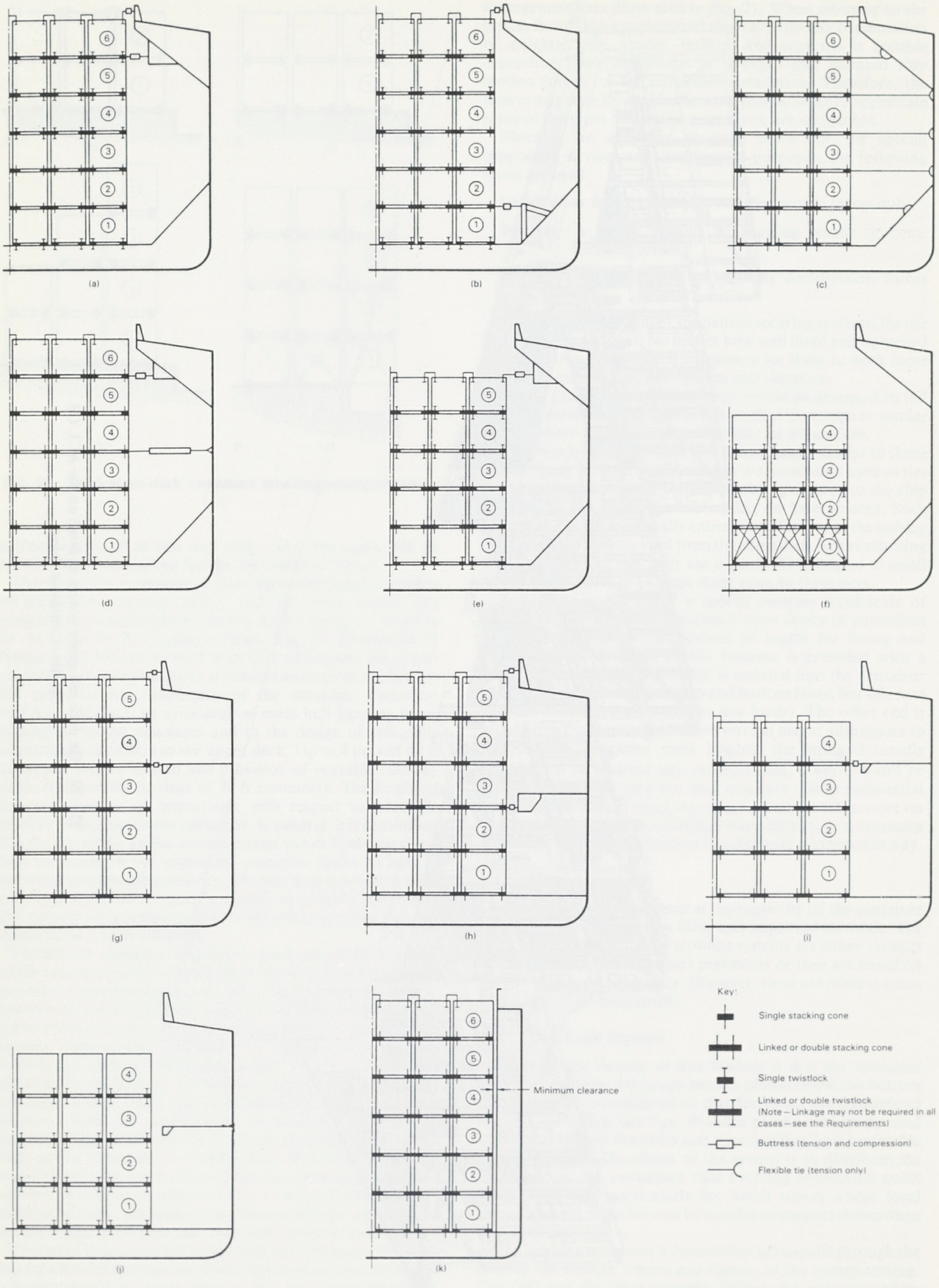


Fig. 21 Typical in-hold container securing arrangements

force of one half the rated weight on each bottom frame to the corner casting connection, this limiting criterion is utilised to define an acceptable line load stowage.

Stacking cones are placed at the corners to prevent any transverse movement of the container or, where tipping forces may occur, twistlocks (or external lashings) are fitted. The height of the line support must be such that the corner casting is not resting on the ship structure, but if a twistlock is used to prevent lifting this may require to be of special long shaft design to permit complete locking.

A second tier may be fitted using conventional corner fittings. Line loading is not permitted between containers as the top frame and side wall are not designed for this mode of loading. The weight of the second tier is to be such that the maximum total compressive force in the lower tier corner post (and hence to the bottom frame) does not exceed one half the rated weight of the container. In practice, this limits the upper tier to about 10 tonnes (20 ft) or 15 tonnes (40 ft) for most arrangements.

5.1.2 **Close Stowage**

Systems have been approved, Fig. 21k, where the containers are stowed in holds with minimal gap (25 mm) between adjacent rows and between the outside row at the ship structure. Cones are fitted between tiers with link plates between stacks and the containers are allowed to deflect under racking and rest on a longitudinal bulkhead or similar structure at the side of the hold. The usual criteria apply with regard to racking (which is most severe at the bottom tier) and container compression. Although the clearances have to be small and there is an apparent risk of small movements jamming containers, the system seems to have been successfully applied in a number of ships.

5.1.3 **Reduced Fixing Points**

Although not strictly a different system, this may be an appropriate place to mention that securing points to the deck are occasionally omitted in stows on the enclosed vehicle decks of Ro-Ro ships where containers may be stowed very close together. In such stows it is impracticable to obtain access to fit securing devices at every corner. However, at least two corners of each container must be restrained, but the fittings at one or both of the remaining two may be omitted provided the calculations do not indicate that any allowable force would thereby be exceeded. Small lifting forces at the "free" corners have been accepted in such stowages on the grounds that the container will rest on the adjacent stack. The end stack must, of course, be properly supported in these circumstanmces.

6. ACKNOWLEDGEMENTS

The Authors wish to acknowledge with thanks the co-operation and assistance which has been given to the Society by a number of manufacturers in developing and codifying a basis for examining container securing arrangements.

The Authors also thank colleagues who have been involved in the development of the calculation methods and in the preparation and presentation of this paper.

7. REFERENCES

1. International Standards Organisation (ISO) Series I Freight Containers.
   ISO 668:"1979 Classification, External Dimensions and Ratings".
   ISO 1161:"1980 Corner Fittings—Specifications".
   ISO 1496:"1978 Specification and Testing".
2. International Maritime Organisation (IMO).
   International Convention for Safe Containers 1977.
3. "Requirements for Freight Container Securing Arrangements", Lloyd's Register of Shipping, ed 1980, 1981 and 1984.
4. "Protection and Securing of Deck Stowed Containers", C. R. Cushing, SNAME 1969.
5. "Guidelines for Deck Stowage of Containers", US Maritime Administration—J. J. Henry Co. Inc. 1970.
6. "Design of on-deck Container Securing Systems", K-T Liu and R. K. Michel, SNAME 1976.
7. "Shipboard Control and Lashing Techniques", M. J. Carter, 1972.
8. "General Principles of the Science of Securing System Design", P. D. James 1979.
9. "Consideration for Modern Container, Trailer and General Cargo Securing Systems", M. Palao, 1981.
10. "A Guide to Selecting Shipboard Container and Trailer Systems", US Maritime Administration—C. R. Cushing & Co. Inc. 1983.
11. "Containerisation International",
    August and September 1983. Also other numbers.
12. "The Securing of ISO Containers, Theory and Practice", A. R. Cole, ICHCA 1981.
13. "Safe Stowage and Securing of Cargo On Board Ships", Research Report. Mariterm AB 1982.
14. "Comparison of Classification Society Rules and Regulations as they Affect Container Loads and Container Securing Systems", R. D. Shultz 1983.

APPENDIX A

CONTAINER SECURING FITTINGS

A.1 General

A.1.1

This Appendix illustrates the principal types of fittings used in shipboard arrangements. A number of compound designs and patent designs exist but the basic principles are in accordance with paragraphs A.2 and A.3. A more detailed discussion of design and operational features is contained in the references, [12] and illustrations of the wide range of fittings available are contained in the catalogues of the major manufacturers.

A.1.2

A comprehensive list of manufacturers of container securing equipment will be found in the appropriate directories. Those manufacturers who have equipment Type Approved by the Society at present are listed in alphabetical order below:

Z.U.O. "Bomet"	Barlinck	Poland
G. Buss	Hamburg	Germany
Conver Ing. Technik	Bremen	Germany
Coubro & Scrutton	Liverpool	U.K.
Fuji Trading	Kobe	Japan
Heinrichs Ing. Technik	Bremen	Germany
Inter Equipos Navales	Madrid	Spain
International Lashing Systems	Antwerp	Belgium
Koei Kinzoku Industries	Mukaishima	Japan
Losinjska Plovidba	Rijeka	Yugoslavia
Mobiltec	Bremen	Germany
Norsaenk-Aalykke	Odder	Denmark
Orsa Kattingfabrik	Orsa	Sweden
Ozean Service & Reparatur	Hamburg	Germany
Peck & Hale	New York	U.S.A.
Spanset Marine	Stockholm	Sweden
Takara Tsusho	Tokyo	Japan
Taiyo Seiki Iron Works	Osaka	Japan
TEC Container	Madrid	Spain
Willi Wader	Radevormwald	Germany

A.2 Fixed Fittings

A.2.1 *Recessed Pot* Fig. A1(a)

This is a cast or fabricated pot of diameter about 150 mm and depth 80 mm. The walls are 11 to 15 mm thick and the top plate, which is often extended as a lip with chamfered edge for welding, is 28 mm thick. The top plate contains an ISO standard slot of width 64 mm and with ends formed by a circle of diameter 124 mm. The slot may be modified to suit vehicle lashing fittings in the decks of Ro-Ro vessels. Multiple fittings of double (transverse), double (longitudinal) or quadruple form are also used.

A.2.2 *Recessed Lashing* Fig. A1(b)

This is a pot of similar dimensions but without top plate. A bar of about 40 mm diameter is fitted instead to provide an anchorage for the hook of a lashing rod or turnbuckle.

A.2.3 *D-ring* Fig. A1(c)

D-rings are usually foldable, being attached by a suitable bow piece, and may be fitted in a shallow recessed dish in order to maintain a flush deck surface. Since it is important that the D-ring does not distort under load it is usually of substantial construction, a section equivalent to 23 mm diameter at the top extending at the base, being typical.

A.2.4 *Dovetails* Fig. A1(d)

In order to achieve a nearly flush attachment for container corner fittings a dovetail fitting is used. The angled bar is attached to the deck, usually forming three sides of the rectangle and the base of the fitting slipped in to the restraint so provided.

Care should be taken to ensure that the dovetails at the two ends (and sides) of the container face in opposite directions, or that other means are provided to prevent the container and securing devices sliding bodily out of the dovetails.

Dovetails are also used vertically on the ship structure to provide an anchorage for buttress fittings while at the same time allowing vertical adjustment of the height of the buttress.

A.2.5 *Foundation Stools* Fig. A1(e)

These are small stools with top plate 28 mm thick, welded to the deck as bottom support for containers.

The stool may be fabricated of appropriate height to compensate for camber and shear in order that the container is stowed level. The design should provide webs in both longitudinal and transverse directions to resist the horizontal shear forces from the containers.

A.3 Loose Securing Devices

A.3.1 *Stacking Cones* Fig. A1(f)

Single stacking cones provide horizontal restraint between successive tiers of containers but cannot resist vertical separation forces.

Double and quadruple stacking cones are used to provide linkage between horizontally adjacent containers. In such arrangements some bending of the plate may occur as the containers move and deflect relative to each other. The plate should not, therefore, be less than 11 mm thick and 13 mm is preferable.

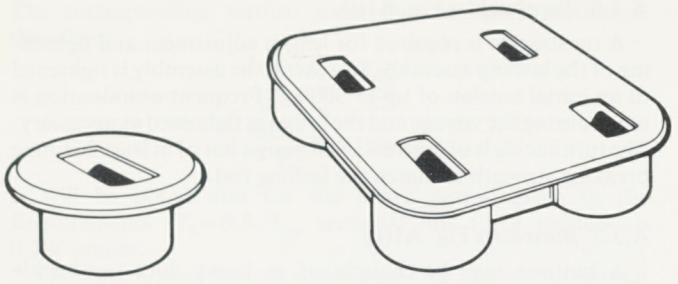
A.3.2 *Twistlocks* Fig. A1(g)

A twistlock is designed to provide vertical restraint in addition to horizontal restraint and consists of a shaft, about 38 mm diameter, turning in a solid body.

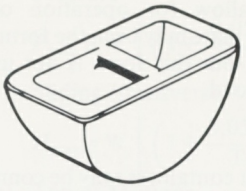
A bottom twistlock may be arranged with a plug and lugs designed to lock in an ISO slot. Alternatively the body may be shaped to fit into a dovetail.

Intermediate twistlocks usually include a double ended shaft although designs do exist where the two parts may be operated independently. The body is extended at mid-depth to form a platform 29 mm thick between the tiers of containers. It should be noted that this is appreciably more than the thickness of the plate of a stacking cone and mixed systems would, therefore, result in the containers suffering racking distortion.

The twistlock is turned by a short handle which is capable of being operated within the 76 mm gap between containers when stowed. It is, however, necessary to be able to verify that all twistlocks are locked. To this end, twistlocks have a top and bottom, or the handles are distinctively shaped and it is usual practice for the twistlock to be locked when the handle is to the left as viewed from above.



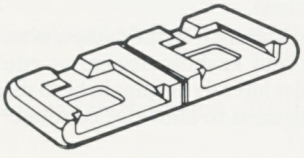
(a) Recessed pots



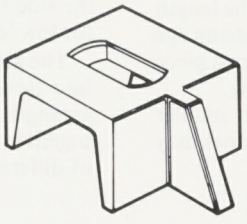
(b) Recessed lashing pot



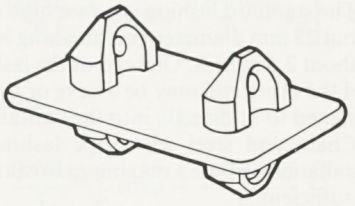
(c) D-Ring



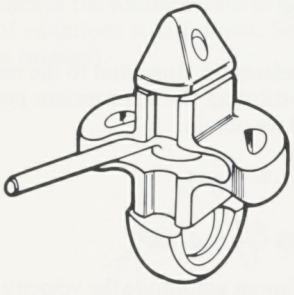
(d) Dovetail shoe (double)



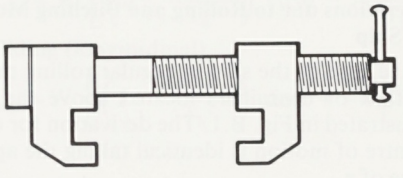
(e) Foundation stool



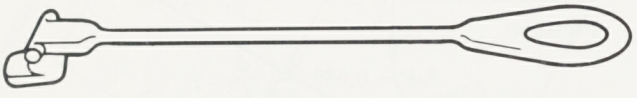
(f) Double stacking cone



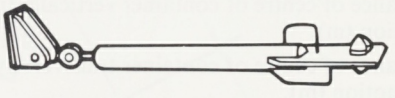
(g) Twistlock



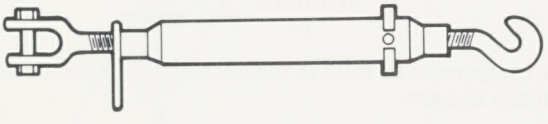
(h) Screwbridge or bridge fitting



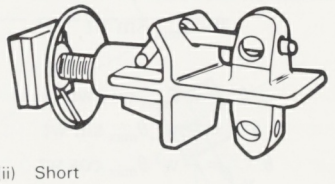
(i) Lashing Rod



k (i) Long



(j) Turnbuckle



k (ii) Short

(k) Buttresses, long and short

Fig. A1 Typical container securing devices

A.3.3 *Linkage Plate*

Where it is required to link adjacent containers where twistlocks are fitted it is usual to use a spectacle piece of suitable scantlings. The design must allow for operation of the twistlocks handle and the linkage plate may be in the form of an E rather than a close spectacle, but this form is not usually suitable for more than 5 tonnes load.

A.3.4 *Screwbridge* Fig. A1(h)

At the top of the stack adjacent containers may be connected by a screwbridge which is a clamp formed from two jaws and a threaded screw. Screwbridges are prone to bending in service as the container stack moves and it is recommended the screw be at least 30 mm diameter.

A.3.5 *Lashings* Fig. A1(i)

The standard lashing is now a high strength alloy steel rod of about 25 mm diameter and breaking load 36 tonnes. The length is about 2,5 metres. One end of the lashing is formed into an eye and the other end may be an eye or a special shaped head piece designed to fit directly into the container corner casting.

Chain and steel wire rope lashings are used for smaller installations where a maximum breaking load of 20 tonnes may be sufficient.

A.3.6 *Turnbuckles* Fig. A1(j)

A turnbuckle is required for length adjustment and tightening of the lashing assembly. In general the assembly is tightened to an initial tension of up to 500 kg. Frequent examination is made during the voyage and the lashings tightened as necessary. The turnbuckle is of conventional design but of at least 36 tonne breaking strength to match the lashing rod.

A.3.7 *Buttresses* Fig. A1(k)

A buttress may be thought of as heavy duty turnbuckle capable of accepting tension or compression loading. That is, it consists of a heavy body and a screw adjustment. The connection to the containers is made for intermediate levels, by an intermediate stacking cone with its plate forming part of the buttress. Buttresses designed for use at the top of the stack use a pinlock cone or twistlock shaft in order to prevent the attachment jumping out of the corner casting. Attachment to the side face of the corner casting is not recommended except for low loads (under 10 tonnes).

The attachment to ship structure is made using a plate fitting into dovetail rails, a plug and keyhole device, or equivalent arrangements which provides lateral restraint in both directions together with vertical adjustment to allow for container stacks of different heights.

APPENDIX B

DERIVATION OF EQUATIONS FOR THE CALCULATIONS

B.1 Accelerations due to Rolling and Pitching Motions of the Ship

Consider the case of the ship in regular rolling motion and consider a stack of containers located above the centre of motion as illustrated in Fig. B.1. The derivation for containers below the centre of motion is identical taking the appropriate negative value of z_m.

The following symbols will be used:

θ = angle of roll (radians).

ϕ = angle of roll (degrees).

w = angular velocity (radians/sec).

T_r = rolling period (seconds).

W = weight of the container (tonnes).

z_m = distance of centre of container vertically from centre of motion (m).

y = distance of centre of container transversely from centre of motion (m).

r = radius of centre of container from O_m (m).

Then, at any instant in the roll:

$$\theta = \theta_{max} \sin wt$$

Whence

$$\theta' = w\,\theta_{max} \cos wt$$

$$\theta'' = -w^2\,\theta_{max} \sin wt$$

$$\theta''' = -w^3\,\theta_{max} \cos wt$$

But, for maximum acceleration $\theta''' = 0$.

Hence $\cos wt = 0$

$$w = \frac{2\pi}{t} \text{ and } \sin wt = 1$$

That is,

$$\theta'' = -w^2\,\theta_{max}$$

$$= -\frac{4\pi^2}{t^2}\,\theta_{max}$$

Now, the maximum linear acceleration tangential to the radius of motion is obtained by substituting the appropriate period and amplitude of motion, and we obtain:

$$\theta'' r = -\frac{4\pi^2}{T_r^2} \cdot \phi \frac{\pi}{180} \cdot r$$

$$= -0{,}689 \frac{\phi . r}{T_r^2} \text{ rad/sec}^2.$$

Note that, at the point of maximum amplitude the velocity and hence the radial acceleration is zero.

Resolving the acceleration into components parallel to and normal to the vertical axis of the container stack, and introducing the weight of container, we obtain the components of force as follows:

Pressure:

$$P = 0{,}689 \frac{W}{g} \cdot \frac{\phi}{T_r^2} \cdot y$$

$$= \frac{0{,}07024W}{T_r^2}\,\phi\, y \text{ tonnes}$$

Transverse:

$$H = 0{,}689 \frac{W}{g} \cdot \frac{\phi}{T_r^2} \cdot z_m$$

$$= \frac{0{,}07024W}{T_r^2}\,\phi\, z_m \text{ tonnes}$$

The components of force in the pitching condition are derived similarly and are:

Pressure:

$$P = \frac{0{,}07024W\,\psi x}{T_p^2} \text{ tonnes}$$

Longitudinal:

$$J = \frac{0{,}07024W\,\psi z_m}{T_p^2} \text{ tonnes}$$

The maximum amplitude of heave is taken as $\frac{L_{pp}}{80}$ metres.

The corresponding vertical force due to heave motion is therefore:

$$\frac{W}{g} \cdot \frac{4\pi^2}{T_h^2} \cdot \frac{L_{pp}}{80}$$

$$= \frac{0{,}05L_{pp}}{T_h^2} \text{ W tonnes}$$

It will be noted that for the heave period given in the Requirements ($T_h = 0{,}5\sqrt{L_{pp}}$ seconds) this force reduces to 0,2W tonnes.

The force is resolved into components parallel to and normal to the vertical axis of the container stack, leading to:

Pressure:

Roll Motion $\frac{0{,}05L_{pp}W}{T_h^2} \cos\phi$ tonnes

Pitch Motion $\frac{0{,}05L_{pp}W}{T_h^2} \cos\psi$ tonnes

Sliding:

(Transverse) Roll Motion $\frac{0{,}05L_{pp}W}{T_h^2} \sin\phi$ tonnes

(Longitudinal) Pitch Motion $\frac{0{,}05L_{pp}W}{T_h^2} \sin\psi$ tonnes

B.2 Forces on a Container in the Stack

The components of force on a particular container are derived in accordance with Section B.1 and the complete set of components is given in Table 4. The components are summed for each of the combinations of motions given in 4.3 and the full set of equations is as follows. See also Fig. B.1. Q is the wind force (tonnes).

(i) Rolling Condition:

(a) Bottom of Motions:

Pressure

$$P_{max} = W\left[\left(1 + \frac{0{,}05L_{pp}}{T_h^2}\right)\cos\phi + \frac{0{,}07024\phi}{T_r^2}\,y\right]$$

Sliding (transverse)

$$H_{max} = W\left[\left(1 + \frac{0{,}05L_{pp}}{T_h^2}\right)\sin\phi + \frac{0{,}07024\phi}{T_r^2}\,z_m\right] + Q$$

(b) Top of Motions,

Pressure

$$P_{min} = W\left[\left(1 - \frac{0{,}05L_{pp}}{T_h^2}\right)\cos\phi - \frac{0{,}07024\phi}{T_r^2}\,y\right]$$

Sliding (transverse)

$$H_{min} = W\left[\left(1 - \frac{0{,}05L_{pp}}{T_h^2}\right)\sin\phi + \frac{0{,}07024\phi}{T_r^2}\,z_m\right] + Q$$

(ii) Pitching Condition:

(a) Bottom of Motions,

Pressure

$$P_{max} = W\left[\left(1 + \frac{0{,}05L_{pp}}{T_h^2}\right)\cos\psi + \frac{0{,}07024\psi}{T_p^2}\,x\right]$$

Sliding (longitudinal)

$$J_{max} = W\left[\left(1 + \frac{0{,}05L_{pp}}{T_h^2}\right)\sin\psi + \frac{0{,}07024\psi}{T_p^2}\,z_m\right]$$

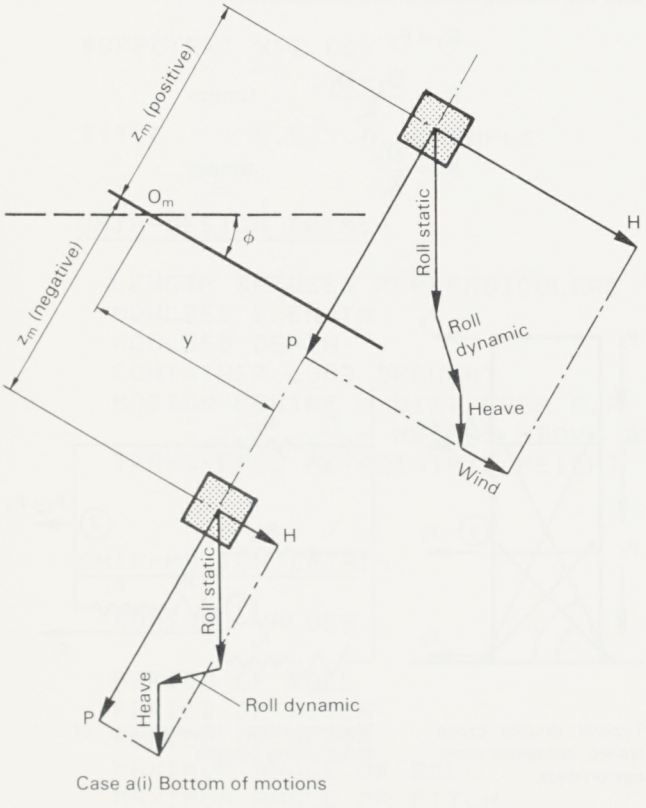
(b) Top of Motions,

Pressure

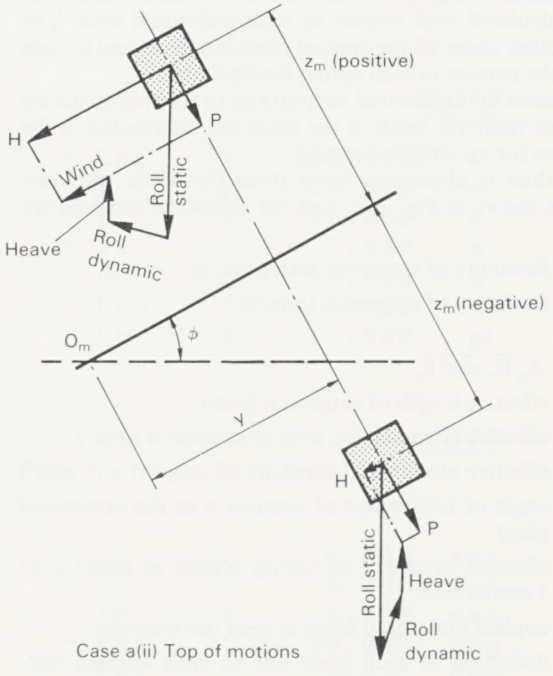
$$P_{min} = W\left[\left(1 - \frac{0{,}05L_{pp}}{T_h^2}\right)\cos\psi - \frac{0{,}07024\psi}{T_p^2}\,x\right]$$

Sliding (longitudinal)

$$J_{min} = W\left[\left(1 - \frac{0{,}05L_{pp}}{T_h^2}\right)\sin\psi + \frac{0{,}07024\psi}{T_p^2}\,z_m\right]$$



Case a(i) Bottom of motions



Case a(ii) Top of motions

Fig. B1 Components of force on one container in the rolling condition

(iii) Combined Condition:

(a) Bottom of Motions,

Pressure

$$P_{max} = W\left[\left(\cos 0{,}71\phi \cos 0{,}71\psi\right) + 0{,}04987\left(\frac{\phi y}{T_r^2} + \frac{\psi x}{T_p^2}\right)\right]$$

Sliding (transverse)

$$H_{max} = W\left[\sin 0{,}71\phi + \frac{0{,}04987\phi}{T_r^2} z_m\right] + Q$$

Sliding (longitudinal)

$$J_{max} = W\left[\sin 0{,}71\psi + \frac{0{,}04987\psi}{T_p^2} z_m\right]$$

(b) Top of Motions,

Pressure

$$P_{min} = W\left[\left(\cos 0{,}71\phi \cos 0{,}71\psi\right) - 0{,}04987\left(\frac{\phi y}{T_r^2} + \frac{\psi x}{T_p^2}\right)\right]$$

Sliding (transverse)

$$H_{min} = W\left[\sin 0{,}71\phi + \frac{0{,}04987\phi}{T_r^2} z_m\right] + Q$$

Sliding (longitudinal)

$$J_{min} = W\left[\sin 0{,}71\psi + \frac{0{,}04987\psi}{T_p^2} z_m\right]$$

B.3 Calculation of Forces in Supported Stacks

The method adopted by the Society is to model the container stack and supports as a system of springs of appropriate flexibility. The method is equally applicable to lashings or to buttress type supports.

The resultant loads in the container stack, calculated in accordance with the Requirements, are applied systematically to the idealised spring system and the deflection at each node point is calculated with respect to each individual load. The total deflection under all the applied loads is determined at each node and the tension in each spring is calculated.

The tensions in the external supports go to the ship structure and the nett resultant loads in the stack are distributed in the same way as for an unlashed stack.

The method is illustrated for a three tier stack with two lashings as shown in Fig. B.2, and the following symbols are used:

K_c = flexibility of container wall (mm/t).

K_{Ln} = flexibility of support n (mm/t)

$$= \frac{L_n}{A_n E_n \cos^2 \theta_n}$$

L_n = effective length of support n (mm).

A_n = effective cross-section area of support n (mm^2)

E_n = effective modulus of elasticity of support n (t/mm^2)

θ_n = angle of inclination of support n to the horizontal (deg)

K_1 to K_5 = effective flexibility of spring system at nodes 1 to 5 mm/tonne.

F_0 to F_3 = applied horizontal force at each tier (tonnes).

δ_f = deflection at each node due to each applied horizontal force (mm).

D_n = overall deflection at each support (mm).

T_n = tension in each support (tonnes).

Then, the effective flexibility at each node is:

$$K_1 = \frac{K_{L1} K_c}{K_{L1} + K_c} \quad ; \quad K_2 = K_{L2} + K_c$$

$$K_3 = \frac{K_1 K_2}{K_1 + K_2} \quad ; \quad K_4 = K_1 + K_c$$

$$K_5 = \frac{K_4 K_{L2}}{K_4 + K_{L2}}$$

And the deflection at nodes are:

For F_1

$$\delta_1 = F_1 . K_3 \quad ; \quad \delta_2 = F_1 . K_3 . \frac{K_{L2}}{K_2}$$

For $F_4 (= F_2 + F_3)$

$$\delta_1 = F_4 . K_5 . \frac{K_1}{K_4} \quad ; \quad \delta_2 = F_4 . K_5$$

Hence the total deflection at each node support is:

$$D_1 = F_1 K_3 + F_4 . K_5 \frac{K_1}{K_4}$$

$$D_2 = F_1 K_3 . \frac{K_{L2}}{K_2} + F_2 K_3$$

The horizontal component of tension at each support is:

$$T_n = \frac{D_n}{K_n}$$

and, resolving this, we obtain the tension in each lashing:

$$T_2 \text{ (upper lashing)} = \frac{D_2}{K_{L2} \cos\beta} \quad \text{tonnes}$$

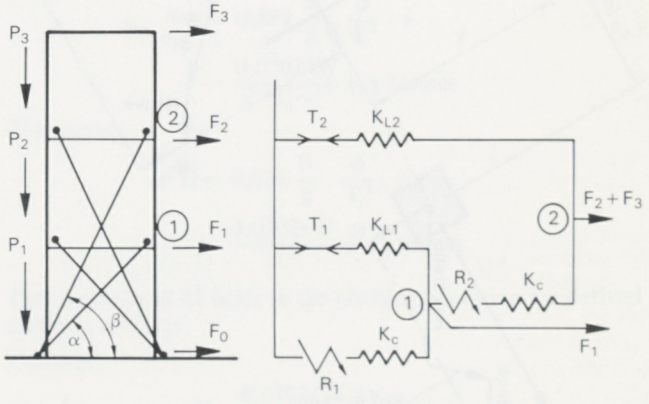
$$T_1 \text{ (lower lashing)} = \frac{D_1}{K_{L1} \cos\alpha} \quad \text{tonnes}$$

and the racking force in the containers is:

$$R_3 = F_3$$

$$R_2 = \frac{D_2 - D_1}{K_c} \quad \text{tonnes}$$

$$R_1 = \frac{D_1}{K_c} \quad \text{tonnes}$$



Typical double cross-lashed container stowage on deck

Mathematical idealisation of force/spring system

Fig. B2 Lashed stack and spring model

APPENDIX C

WORKED EXAMPLE OF DTC OUTPUT

Two stacks are illustrated, as follows:

1. A three tier stack of 20 ft containers located on a hatch about 0,25L forward of midships.

   Container weights 15 + 15 + 15 = 45 tonnes total
   Secured by twistlocks only.

   It will be noted that racking in the rolling condition is approaching the allowable limit.

2. A six tier by six row block of 40 ft containers in an aft hold supported by tension and compression buttresses at levels 5/6 and top of stack. Weights 24 tonnes per container throughout.
   The calculation is made for three rows supported by the buttresses on one side of the hold and is made for the door end (wall spring constant 2,85 mm/tonne) and the closed end (0,65 mm/tonne).
   The output racking and compression forces are per container. It will be noted they are acceptable but separation occurs at levels 3/4 and 4/5, requiring the use of twistlocks at these levels.
   The buttress forces are the working loads based on three rows. The corresponding compression in the container frames (*see* 4.9) is acceptable.

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**********************************************************************
**                  - LLOYD'S REGISTER OF SHIPPING -                  **
**                                                                    **
**                        PROGRAM NO. :  20801/R1                     **
**                        CARTRIDGE   : LZDC8A                        **
**                        PROGRAM DATE: JUL 84                        **
**                                                                    **
**               LOADS FOR FREIGHT CONTAINER SECURING                 **
**                  ARRANGEMENTS - UNLASHED STACKS                    **
**********************************************************************
BUILDERS:  ABC CO.                                  DATE    :3.12.84

YARD NOS:  000                                      INITIALS:A.J.W.
----------------------------------------------------------------------

SUPPLIER: XYZ CO.


TITLE   : L.R.T.A. EXAMPLE


SHIP-DESIGN DATA:-                                              UNITS

  LENGTH BETWEEN PERPENDICULARS        - Lpp    :   180.000    m
  MOULDED BREADTH                      - B      :    28.000    m
  MOULDED DEPTH                        - D      :    16.000    m
  CONTAINER LOAD DRAUGHT               - Tc     :     7.500    m
  MOTION CENTRE - DIST FROM A.P.       - Mcl    :    90.000    m
                - HEIGHT ABOVE BASE    - Mch    :     8.000    m
  TRANSVERSE METACENTRIC HEIGHT        - Gm     :     1.500    m


SHIP-MOTION DATA:-                                              UNITS

  NOMINAL VALUES

  PERIOD OF ROLL                       - Tr     :    16.003  sec
  PERIOD OF PITCH                      - Tp     :     6.708  sec
  PERIOD OF HEAVE                      - Th     :     6.708  sec
  MAXIMUM ANGLE OF ROLL                - Phi    :    30.000  deg
  MAXIMUM ANGLE OF PITCH               - Psi    :     6.625  deg
  WIND VELOCITY                        - V      :    40.000  m/s

  CALCULATED AMPLITUDE OF HEAVE                 :     2.25   m
```

FORCES IN THE STACK - ROLLING CONDITION

TITLE: L.R.T.A. EXAMPLE

STACK - BAY 09 HATCH 20FT OUTER STACK

DISTANCE STACK CENTRE FROM:
A.P. : 135.00 (m)
PITCH CENTRE : 45.00 (m)
C.L. : 6.30 (m)
BASE DIMENSIONS : 6.06 x 2.44 (m)

ORIENTATION : FORE AND AFT

CONTAINER TIER	VCG ABV. BASE (m)	HEIGHT HT (m)	WIND FORCE (t)
3	24.100	2.591	1.794
2	21.500	2.591	1.794
1	18.900	2.591	1.794

NOTE * - ALLOWABLE VALUE EXCEEDED.

ACCELERATION FACTORS

TIER	VERTICAL		TRANSVERSE		LONGITUDINAL	
	MAX	MIN	MAX	MIN	MAX	MIN
3	1.091	0.641	0.732	0.532	0.000	0.000
2	1.091	0.641	0.711	0.511	0.000	0.000
1	1.091	0.641	0.690	0.490	0.000	0.000

LOADS AND FORCES (Tonnes)

TIER	CONTAINER WEIGHT	COMPRESSIVE FORCE PER BASE CORNER MAXIMUM	MINIMUM1	MINIMUM2
3	15.00	6.51	1.67	0.51
2	15.00	19.75	-3.39	-4.11
1	15.00	39.55	-15.01	-13.70

TIER	RACKING FORCE PER WALL TRANS	LONGL	SHEAR FORCE PER CORNER TRANS	LONGL
3	2.28	0.00	3.51	0.00
2	8.62	0.00	6.94	0.00
1	14.79	0.00	10.28	0.00

****

FORCES IN THE STACK - PITCHING CONDITION

TITLE: L.R.T.A. EXAMPLE

STACK - BAY 09 HATCH 20FT OUTER STACK

DISTANCE STACK CENTRE FROM:
A.P. : 135.00 (m)
PITCH CENTRE : 45.00 (m)
C.L. : 6.30 (m)
BASE DIMENSIONS : 6.06 x 2.44 (m)

ORIENTATION : FORE AND AFT

CONTAINER TIER	VCG ABV. BASE (m)	HEIGHT HT (m)	WIND FORCE (t)
3	24.100	2.591	1.794
2	21.500	2.591	1.794
1	18.900	2.591	1.794

NOTE * - ALLOWABLE VALUE EXCEEDED.

ACCELERATION FACTORS

TIER	VERTICAL		TRANSVERSE		LONGITUDINAL	
	MAX	MIN	MAX	MIN	MAX	MIN
3	1.657	0.329	0.000	0.000	0.305	0.259
2	1.657	0.329	0.000	0.000	0.278	0.232
1	1.657	0.329	0.000	0.000	0.251	0.205

LOADS AND FORCES (Tonnes)

TIER	CONTAINER WEIGHT	COMPRESSIVE FORCE PER BASE CORNER MAXIMUM	MINIMUM1	MINIMUM2
3	15.00	7.02	5.41	0.48
2	15.00	15.94	8.92	-0.79
1	15.00	26.67	10.62	-3.73

TIER	RACKING FORCE PER WALL TRANS	LONGL	SHEAR FORCE PER CORNER TRANS	LONGL
3	0.45	0.76	0.49	1.26
2	1.35	2.98	0.99	2.40
1	2.24	5.00	1.48	3.44

****

FORCES IN THE STACK - COMBINED CONDITION

TITLE: L.R.T.A. EXAMPLE

STACK - BAY 09 HATCH 20FT OUTER STACK

DISTANCE STACK CENTRE FROM:
A.P. : 135.00 (m)
PITCH CENTRE : 45.00 (m)
C.L. : 6.30 (m)
BASE DIMENSIONS : 6.06 x 2.44 (m)

CONTAINER TIER	VCG ABV. BASE (m)	HEIGHT HT (m)	WIND FORCE (t)
3	24.100	2.591	1.794
2	21.500	2.591	1.794
1	18.900	2.591	1.794

ORIENTATION : FORE AND AFT

NOTE * - ALLOWABLE VALUE EXCEEDED.

ACCELERATION FACTORS

TIER	VERTICAL MAX	VERTICAL MIN	TRANSVERSE MAX	TRANSVERSE MIN	LONGITUDINAL MAX	LONGITUDINAL MIN
3	1.296	0.561	0.457	0.457	0.200	0.200
2	1.296	0.561	0.442	0.442	0.181	0.181
1	1.296	0.561	0.427	0.427	0.162	0.162

LOADS AND FORCES (Tonnes)

TIER	CONTAINER WEIGHT	COMPRESSIVE FORCE PER BASE CORNER MAXIMUM	MINIMUM1	MINIMUM2
3	15.00	6.76	2.95	0.20
2	15.00	18.70	0.73	-4.78
1	15.00	35.64	-6.48	-14.74

TIER	RACKING FORCE PER WALL TRANS	RACKING FORCE PER WALL LONGL	SHEAR FORCE PER CORNER TRANS	SHEAR FORCE PER CORNER LONGL
3	1.59	0.50	2.38	0.83
2	5.88	1.95	4.70	1.57
1	10.06	3.27	6.95	2.24

****

```
**********************************************************************
**                - LLOYD'S REGISTER OF SHIPPING -                  **
**                                                                  **
**                        PROGRAM NO. :  20802/R1                   **
**                        CARTRIDGE   : LZDC8A                      **
**                        PROGRAM DATE: JUL 84                      **
**                                                                  **
**              LOADS FOR FREIGHT CONTAINER SECURING                **
**                 ARRANGEMENTS - LASHED STACKS                     **
**********************************************************************
BUILDERS:  ABC CO.                                DATE    :3.12.84

YARD NOS:  000                                    INITIALS:A.J.W.
----------------------------------------------------------------------

SUPPLIER: XYZ CO.

TITLE   :  L.R.T.A.EXAMPLE

STACK - BAY 24 NO 5 HOLD 40FT STACK


STACK DATA:-                                              UNITS

  NUMBER OF STACKS              - Nr :        3.000
  TIERS PER STACK               - Nc :        6
  CONTAINER LENGTH              - La :       12.192     m
            BREADTH             - Lb :        2.440     m
  STACK ORIENTATION                  : LONGITUDINAL


SUPPORTS DATA:-

-------------------------------------------------------------------------------
SUPPORT SUPPORT DESCRIPTION  LENGTH  MODULUS OF  CROSS SEC.  HORIZ.  VERTIC.
        TO TIER                      ELASTICITY     AREA      SPAN     SPAN
                              (m)    (kgf/mm2)     (cm2)      (m)      (m)
-------------------------------------------------------------------------------
  6       6      BUTTRESS    0.50  1.200E+04      10.00     0.50     0.00
  5       6      BUTTRESS    0.80  1.200E+04      15.00     0.80     0.00
  4       5      NO SUPPORT
  3       4      NO SUPPORT
  2       3      NO SUPPORT
  1       2      NO SUPPORT
```

FORCES IN THE SUPPORTS AND CONTAINERS
WALL SPRING CONSTANT: 0.65 mm/t

TITLE: L.R.T.A.EXAMPLE

STACK - BAY 24 NO 5 HOLD 40FT STACK

STACK ORIENTATION : FORE & AFT.
SUPPORT ALIGNMENT : ATHWART.

CONTAINER BASE DIMENSIONS : 12.19 X 2.44 m.

NO. OF STACKS : 3

CONTAINER TIER	HEIGHT HT (m)	WIND FORCE (t)
6	2.591	0.000
5	2.591	0.000
4	2.591	0.000
3	2.591	0.000
2	2.591	0.000
1	2.591	0.000

CONTAINER DATA AND SUPPORT FORCE:-

TIER	TOTAL WEIGHT OF TIER (t)	HORIZ. ACCN.	VERTIC. ACCN.	SUPPORT TO TIER	SUPPORT FORCE (t)
6	72.000	0.662	1.090	6	16.435
5	72.000	0.640	1.090	6	56.799
4	72.000	0.619	1.090	5	NO SUPPORT
3	72.000	0.598	1.090	4	NO SUPPORT
2	72.000	0.576	1.090	3	NO SUPPORT
1	72.000	0.555	1.090	2	NO SUPPORT

N.B.:- FORCES IN SUPPORTS ARE NOT COMPARED WITH MAXIMUM ALLOWABLE VALUES.

LOADS AND REACTIONS PER STACK

TIER I	RACKING FORCE IN WALL Rk (tonnes)	SHEAR FORCE AT CORNER Sh (tonnes)	COMP FRCE AT CORN.A Vc-lhs (tonnes)	COMP FRCE AT CORN.B Vc-rhs (tonnes)	TOP CORN. DISPLAC. (mm)
6	2.830	-1.356	9.55	3.53	0.68
5	13.907	4.833	30.85	-4.69	2.52
4	6.311	0.748	44.10	-4.86	11.56
3	1.033	-3.199	49.54	2.78	15.67
2	8.121	-7.001	47.46	17.94	15.00
1	14.949	-10.664	38.12	40.36	9.72

* - EXCEEDS MAXIMUM ALLOWABLE VALUE.

FORCES IN THE SUPPORTS AND CONTAINERS
WALL SPRING CONSTANT: 2.85 mm/t

TITLE: L.R.T.A.EXAMPLE

STACK - BAY 24 NO 5 HOLD 40FT STACK

STACK ORIENTATION : FORE & AFT.
SUPPORT ALIGNMENT : ATHWART.

CONTAINER BASE
DIMENSIONS : 12.19 X 2.44 m.

NO. OF STACKS : 3

CONTAINER TIER	HEIGHT HT (m)	WIND FORCE (t)
6	2.591	0.000
5	2.591	0.000
4	2.591	0.000
3	2.591	0.000
2	2.591	0.000
1	2.591	0.000

CONTAINER DATA AND SUPPORT FORCE:-

TIER	TOTAL WEIGHT OF TIER (t)	HORIZ. ACCN.	VERTIC. ACCN.	SUPPORT TO TIER	SUPPORT FORCE (t)
6	72.000	0.662	1.090	6	10.499
5	72.000	0.640	1.090	6	64.462
4	72.000	0.619	1.090	5	NO SUPPORT
3	72.000	0.598	1.090	4	NO SUPPORT
2	72.000	0.576	1.090	3	NO SUPPORT
1	72.000	0.555	1.090	2	NO SUPPORT

N.B.:- FORCES IN SUPPORTS ARE NOT COMPARED WITH MAXIMUM ALLOWABLE VALUES.

LOADS AND REACTIONS PER STACK

TIER I	RACKING FORCE IN WALL Rk (tonnes)	SHEAR FORCE AT CORNER Sh (tonnes)	COMP FRCE AT CORN.A Vc-lhs (tonnes)	COMP FRCE AT CORN.B Vc-rhs (tonnes)	TOP CORN. DISPLAC. (mm)
6	0.852	-2.444	7.44	5.64	0.44
5	14.483	5.150	29.36	-3.20	2.86
4	6.887	1.064	43.22	-3.98	44.14
3	0.457	-2.883	49.27	3.05	63.77
2	7.545	-6.684	47.80	17.60	62.47
1	14.373	-10.347	39.08	39.40	40.96

* - EXCEEDS MAXIMUM ALLOWABLE VALUE.

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Lloyd's Register Technical Association

POSITIONAL MOORING OFFSHORE

R. C. MACDONALD

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Written contributions to the discussion of this paper are invited from members of the Lloyd's Register Technical Association. To ensure inclusion in the discussion paper, the contributions should be received by the Hon. Secretary in London not later than the 15th April 1985.

Hon. Sec. J. S. Carlton
71 Fenchurch Street, London, EC3M 4BS

POSITIONAL MOORING OFFSHORE

by R. C. Macdonald

SYNOPSIS

This paper describes positional mooring practice offshore and outlines the principles and considerations which apply to the design or evaluation of such mooring systems.

Design standards, environmental criteria, forces and motions, the effects of water depth on mooring performance, catenary behaviour and anchoring are reviewed. Basic design data on these aspects is presented.

The text and diagrams are referenced to the semi-submersible unit but the principles and calculation methods outlined will be largely relevant to any catenary mooring system.

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APPENDIX A Environmental Forces

APPENDIX B Extracts from Lloyd's Register of Shipping's Static Mooring Program SPREAD

1. INTRODUCTION

Alan Buckle's 1972 L.R.T.A. paper on Anchoring and Mooring, one of the few on that subject, gave first class coverage to a wide variety of mooring systems and concepts. This paper is intended, however, to focus on only one activity—offshore positional mooring, an area of increasing involvement for the Society particularly in its role as certifying authority for the United Kingdom Department of Energy.

Positional mooring is the most widely used method of station keeping offshore. While the alternative method of dynamic positioning (D.P.) offers greater mobility, the conventionally moored vessel has the considerable advantage of being able to hold location in extreme environmental conditions, which the D.P. vessel cannot. This key factor plus the very substantial differences in capital and running costs in favour of the moored vessel means that this method of station keeping will continue to be adopted for the majority of unit types.

The Rule basis for the sizing of ships' equipment and the way in which this equipment is used for temporary mooring of the vessel is widely understood. Different principles apply in positional mooring, however, and some knowledge of the terminology and practice involved as well as the more theoretical aspects may benefit the surveyor, especially those directly involved in offshore work.

2. OFFSHORE MOORING PRACTICE

2.1 General Description

Positional moorings in the form of multiple catenary lines are used on mobile offshore units to provide close-order station keeping in the operational role and to hold the vessel on general location in extreme or survival conditions.

The mooring spread is generally laid out in a fairly symmetric array to withstand weather from any direction. The number of mooring lines can vary from four on a limited system used as back-up to dynamic positioning, to as many as sixteen on a very large crane barge. Tension setting and active control of individual wire rope or chain cable lines is done by means of winch or windlass.

Anchors are generally high holding power marine drag types, fitted singly or in tandem, as necessary.

2.2 Anchor Pattern

Before the vessel arrives at its working location the area will have been surveyed, the required global position defined and the anchor pattern chosen.

In active producing areas where fixed platforms, pipelines and wells etc., are already established particular care is needed in planning and laying the mooring: the ideal theoretical spread can seldom be achieved in this situation. The following restrictions are typical of those imposed on operators of mobile units anchoring in the vicinity of a production platform:

(1) No anchors are to be dropped within 200 m of either side of a pipeline or within 200 m of a wellhead.

(2) Mooring lines must be kept at least 10 m clear of any part of the platform structure in all moored conditions.

(3) When running out and recovering anchors, line tensions must be kept high enough to give a minimum clearance of 15 m over a pipeline.

(4) Mooring line tensions are to be maintained at a high enough level in both working and stand-off positions to give at least 15 m clearance over pipeline or wellhead.

(5) No anchor is to be placed within 200 m of another vessel's anchor.

Occasionally a mooring line may have to cross over an already established line from another vessel. This practice, known as cross-mooring, is not desirable but offshore mooring spreads can extend to a diameter of 7 kilometres or more and overlap is sometimes unavoidable. There can be no physical contact allowed between the respective cables since even intermittent touching would lead to rapid localised wear. This is

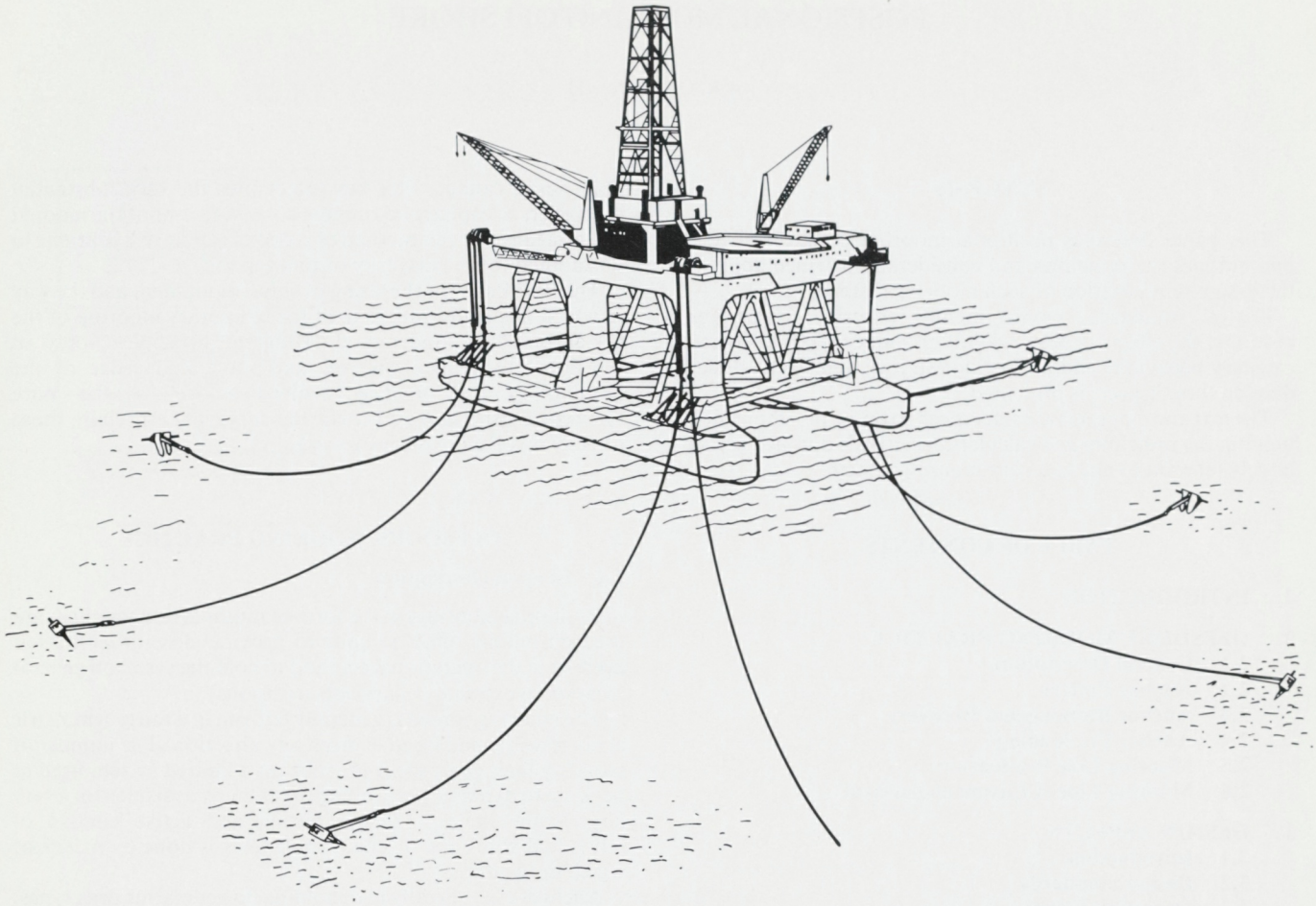


Fig. 1 Typical semi-submersible mooring spread

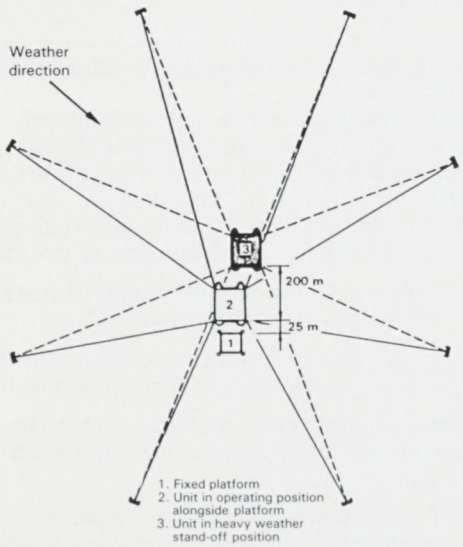


Fig. 2 Anchor pattern of vessel moored alongside fixed installation

believed to have been a factor in a serious mooring failure in the North Sea on a semi-submersible production platform which eventually broke all 12 chain mooring lines in a storm and drifted 25 miles off location.

To avoid this type of problem mooring lines should have a horizontal or vertical clearance of at least 15 m at all times, and this clearance should be in addition to any possible relative cable motion which results from tension changes or vessel heave.

Figure 2 shows a typical anchor pattern for a semi-submersible moored alongside a fixed platform. The vessel will be stationed at *gangway distance* from the platform in its operational mode, but will move some 150-250 m away from the platform in heavy weather to a *stand-off* position to increase its sea room. A sufficient amount of mooring line, beyond the length deployed—at least equal to the stand-off distance—must be kept on board in the chain locker or on the winch drum to permit this movement to take place. The anchor pattern in this type of situation will have been optimised to give the best performance in the stand-off position.

2.3 Anchor Running and Recovery

To achieve the necessary mooring spread, the anchors and mooring lines are run out by anchor handling vessels, with the exception of the first anchor which will normally be dropped by the unit on its approach path to the location.

In estimating bollard pull requirements for this type of operation the horizontal component of tension of a freely suspended cable can be calculated from the following:

$$T = \frac{WS^2}{8d}$$

where W = weight per unit length of cable.
S = horizontal distance between points of suspension.
d = cable sag.

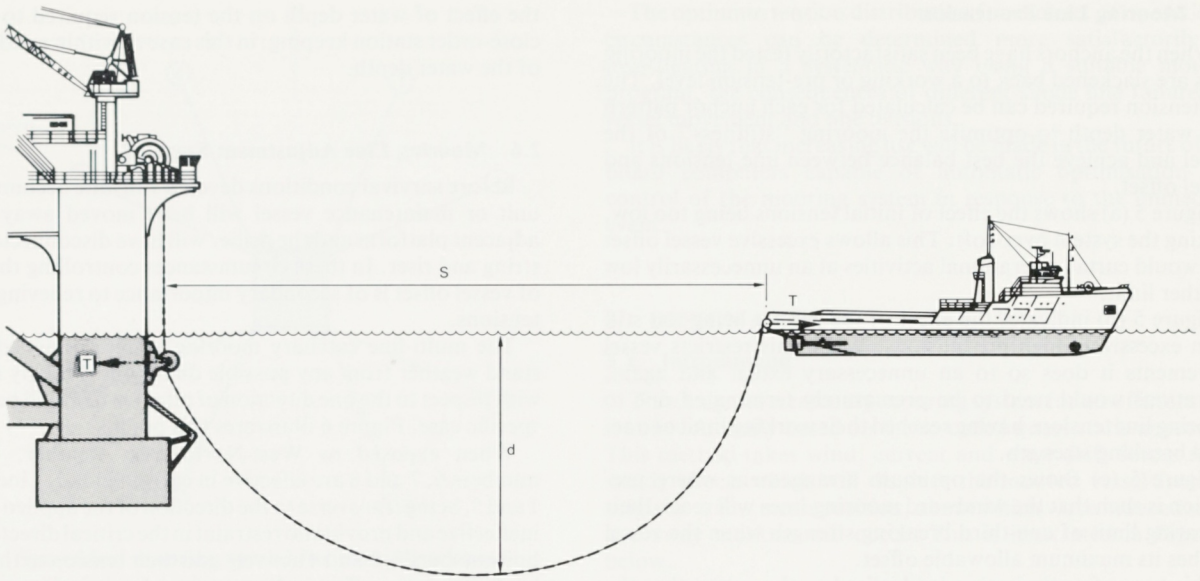


Fig. 3 Running anchor line using handling vessel

The anchor running operation requires close co-ordination between the anchor handler and the parent vessel itself which must match the payout speed of its winches to the forward speed of the anchor handler if stalling the handling vessel—too slow payout—or pile-up of chain cable on the sea-bed—too fast payout—is to be avoided. A specific vertical clearance above the sea-bed may need to be calculated and maintained in certain circumstances to give clearance above a laid pipeline for instance.

The anchors are lowered in turn into their pre-designated positions and to allow eventual breaking-out and recovery of the anchors, pendant wires are attached to the crown or fluke and buoyed off at the surface. Figure 4 shows one such arrangement.

An alternative recovery system preferred by national authorities to pendants and buoys, [1]* which can be a considerable hazard to shipping, is the chain chasing method. With this method the anchors are retrieved by a handling vessel running a closed loop along the cable from the moored vessel's fairlead out to the buried anchor which can then be broken out and hoisted. It may not always be possible, however, for a chaser to reach a deeply embedded anchor and local chain damage can occur by hoisting on a bight of cable rather than by the more robust anchor shank.

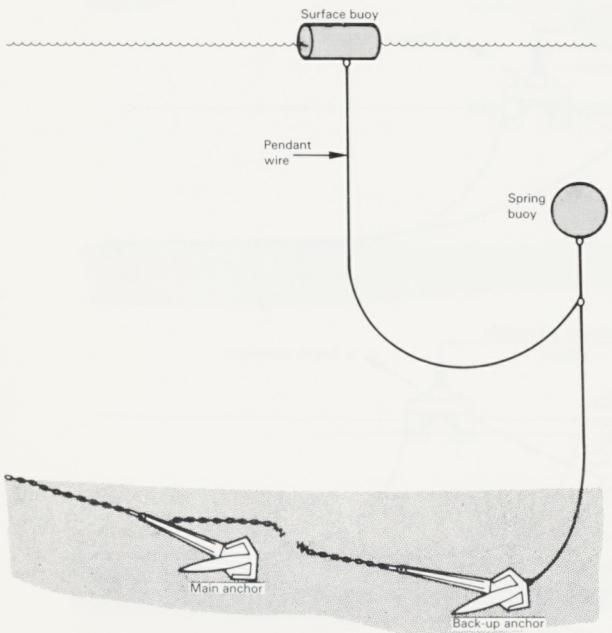


Fig. 4 Anchor marking by pendant and buoy system

2.4 Anchor Pre-loading

When the anchors have been correctly positioned they are pre-loaded by the units own winches to test holding capacity. The position of the vessel is maintained by tensioning opposing anchors simultaneously.

The level of pre-load should be high enough to prove the anchors for survival conditions but need not generally be as high as peak calculated anchor loads.

Advantage can be taken of the fact that capacity will improve after a period of time when the soil has settled and consolidated. Furthermore, in many soils the dynamic loading capability of the anchor will be significantly greater than the slow steady pull performance attainable at test.

A test load in the order of 70-80% of maximum design load should be adequate in most cases, but anchoring is by no means an exact science and scope has to be left for the application of practical experience and individual judgement offshore. The pre-load should not in any case exceed 50% of the mooring line breaking strength.

The test load should be held without significant drop-off for around 15-20 minutes.

Any anchor which fails to hold will be lifted relaid and re-tested, or *piggy-backed*. The latter is a common offshore practice where a second or even third anchor is added in tandem with the first as shown in Fig. 4 to develop the required holding capacity. The distance between anchors with this type of arrangement will be approximately equal to the water depth plus 50 m.

The efficiency of individual anchors is not however maintained in a piggy-back arrangement, as the attitude and performance of the main anchor is adversely affected by the connection of the back-up anchor.

*Numbers in parentheses indicate references.

2.5 Mooring Line Pre-tension

When the anchors have been satisfactorily tested the mooring lines are slackened back to a working or pre-tension level. The pre-tension required can be calculated for each anchor pattern and water depth to optimise the mooring "stiffness" of the vessel and achieve the best balance between line tensions and vessel offset.

Figure 5 (a) shows the effect of initial tensions being too low, making the system over-soft. This allows excessive vessel offset and would curtail operational activities at an unnecessarily low weather limit.

Figure 5 (b) indicates the effect of the system being too stiff from excessively high pre-tensions. While this restricts vessel movements it does so to an unnecessary extent and again, operations would need to be prematurely terminated due to mooring line tensions having reached their working limit of one-third breaking strength.

Figure 5 (c) shows the optimum arrangement where pre-tension is such that the windward mooring lines will reach their operating limit of one-third breaking strength when the vessel reaches its maximum allowable offset.

This type of optimisation is idealised to the extent that the vessel is assumed to be in calm conditions when setting up the mooring and that each line will have the same pre-tension. This is rarely the case in practice as there will generally be some weather influence to add tensions to one side of the mooring, but the optimised values are an essential yardstick to getting the best out of the system.

Figure 10 in Section 3.3 of the paper plots pre-tension values for an eight-line system of wire rope or chain cable. This shows the effect of water depth on the tension required to maintain close-order station keeping; in this case to within a radius of 5% of the water depth.

2.6 Mooring Line Adjustment-Survival

Before survival conditions develop fully the accommodation unit or maintenance vessel will have moved away from its adjacent platform and the driller will have disconnected its drill string and riser. In these circumstances controlling the amount of vessel offset is of secondary importance to relieving high line tensions.

The multi-line catenary mooring system designed to withstand weather from any possible direction, is highly inefficient with respect to the one direction of attack which will occur in the specific case. Figure 6 illustrates this point.

When exposed to West-North-West weather, only line numbers 6, 7 and 8 are effective in carrying load. Line numbers 1 and 5, being transverse to the direction of the applied force, are ineffective and provide no restraint in the critical direction, while line numbers 2, 3 and 4 actively add their tension to the weather load. This latter effect is shown more clearly in Figure 7.

To reduce this negative influence it is common practice offshore to slacken leeward lines (2, 3 & 4 in Figure 6) to the maximum possible extent, and to adjust windward lines (6, 7 & 8) by winch control so that tensions are as close as possible to equality at the limit of vessel surge. The tensions in lines 1 and 5 would be kept at around normal working level to prevent the vessel building up excessive lateral or yawing motions.

This type of line adjustment procedure while minimising

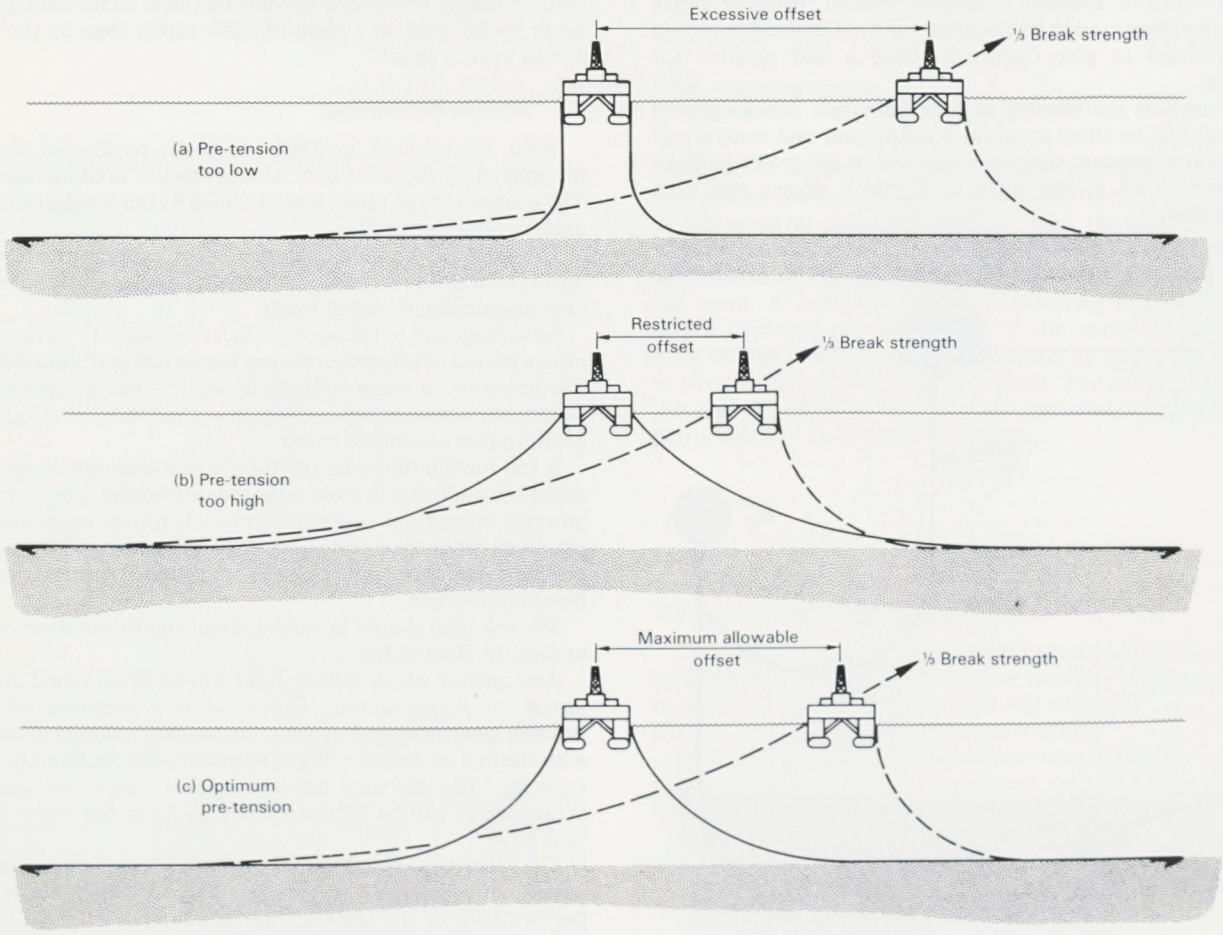


Fig. 5 The effects of mooring line pre-tension on vessel offset

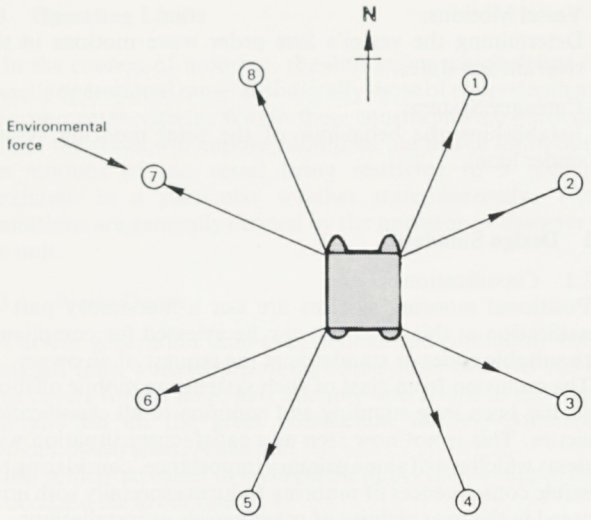


Fig. 6 Symetrical mooring spread for omni-directional environment

tensions in normal circumst nces can be counter-productive in the event of a line failure. In this event the presence of slack lines can allow excessive transient vessel motions and tensions to build up following a line break. (See Figure 21 for typical transient path following line failure).

Notional line adjustment, 100% slackening of all leeward lines etc., has the merit of operational simplicity but does not anticipate or control the accident situation and is consequently, not an adequate basis for design or operation of the system.

The optimum tension distribution for each set of operational circumstances can be determined more satisfactorily by investigating in a systematic way using a suitable motions program, the consequences of different single line failures on vessel movement and line tensions.

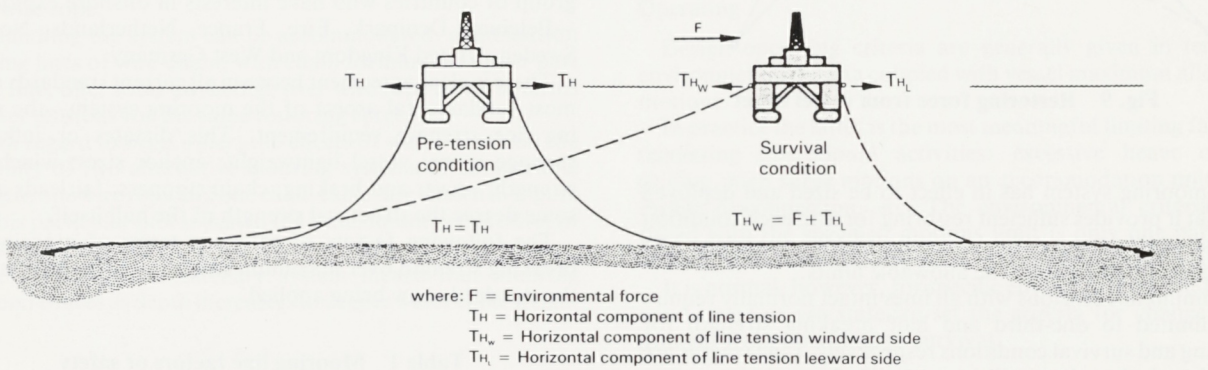
It is likely that increasing use will be made in the future of on-board computers capable of automatic optimisation and control of the mooring system in response to the immediate event.

3. DESIGN ASPECTS

3.1 Introduction

The design of a catenary mooring system for an offshore unit is conventionally based on the so-called quasi-static approach. This method takes wind, current and wave drift forces to be steady effects which will displace the moored vessel from its origin to a new mean position, about which wave induced surge and sway motions will occur. This is illustrated in Figure 8 below.

Position 1	No environmental load on the vessel. Mooring lines under pre-tension only.
Position 2	The new mean position taken up by the vessel under the action of wind, current and mean wave drift forces. Line tensions rise on windward side and reduce on leeward side.
Positions 3 & 4	The upper and lower limits of vessel surge and sway—the first order wave motions. Peak mooring line tensions occur in position 4.



where: F = Environmental force
T_H = Horizontal component of line tension
T_{H_w} = Horizontal component of line tension windward side
T_{H_L} = Horizontal component of line tension leeward side

Fig. 7 Negative effect of leeward mooring lines

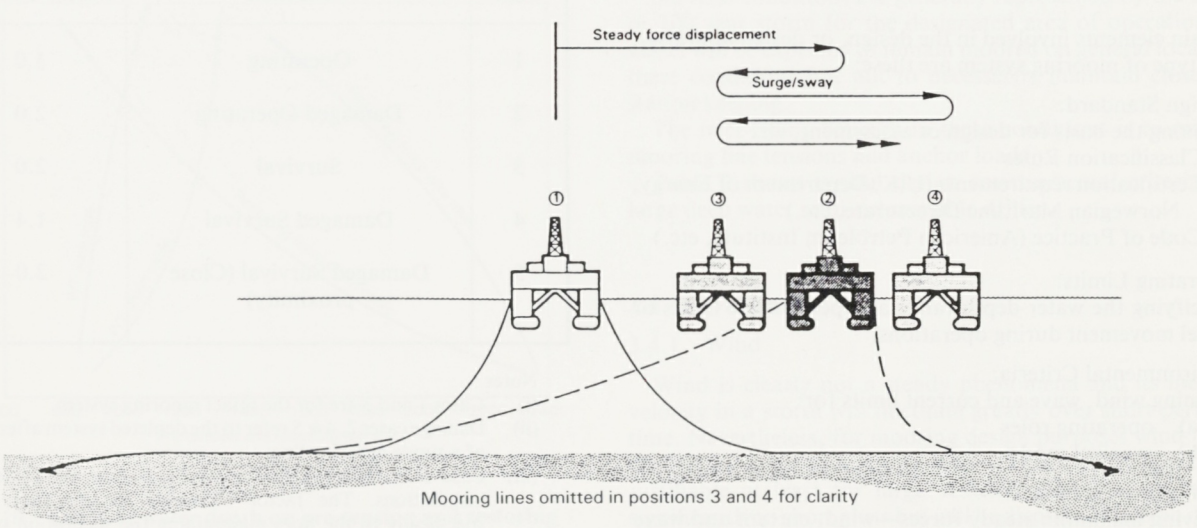


Fig. 8 The quasi-static approach to mooring analysis

Key terms in defining the capability of a multi-line mooring system are *restoring force* and *high line tension*.

Restoring force:

For static balance the applied environmental force is taken to be reacted by mooring line tensions. The vectored sum of these tensions is referred to as the restoring force—the force in other words which would restore the vessel to its original position on removal of the applied load. See Figure 9.

High line tension:

High-line tension is perhaps more self-evident as a term but is specifically the tension in the highest loaded mooring line in the system, at any one time in the motion cycle of the vessel.

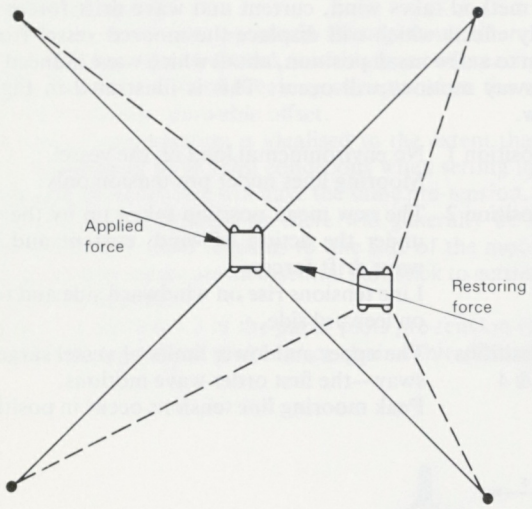


Fig. 9 Restoring force from vessel offset

The mooring system has in effect to be sized and deployed such that it provides sufficient restoring force in each condition to resist environmental forces, while high-line tensions and vessel offset remain within the allowable limits.

Maximum line tensions with all lines intact normally require to be limited to one-third and half breaking strength for operating and survival conditions respectively. Line lengths are selected such that there will be no uplift force at the anchor under maximum loading conditions.

The main elements involved in the design, or design appraisal, of this type of mooring system are these:

Design Standard:
Defining the basis for design or assessment, viz:
- Classification Rules
- Certification requirements (U.K. Department of Energy, Norwegian Maritime Directorate, etc.)
- Code of Practice (American Petroleum Institute, etc.)

Operating Limits:
Specifying the water depth range and permissible limits of vessel movement during operations.

Environmental Criteria:
Defining wind, wave and current limits for:
- (a) operating roles
- (b) survival mode.

Environmental Forces:
Deriving maximum steady forces—wind, current and wave drift—for various headings and conditions.

Vessel Motions:
Determining the vessel's first order wave motions in the relevant sea-states.

Catenary System:
Establishing the behaviour of the total mooring system under load.

3.2 Design Standards

3.2.1 Classification:

Positional mooring systems are not a mandatory part of classification at this time, but can be assessed for compliance with suitable codes or standards at the request of an owner.

The exclusion from class of such systems on mobile offshore units has been long-standing and common to all classification societies. This is not now seen as a satisfactory situation with systems which are of some primary importance, considering the possible consequences of mooring failures especially with units moored in the near vicinity of other vessels or installations.

Rule changes are, therefore, intended which will introduce specific requirements for these systems and bring positional moorings into class.

3.2.2 National Regulations:

The first detailed and comprehensive regulations governing the design, testing and operation of positional mooring systems were produced by the Norwegian Maritime Directorate in a 1982 amendment to their Regulations for Mobile Drilling Platforms.

Similar standards have since been proposed by the Department of Energy for units operating in United Kingdom waters, and it is likely that a voluntary unified standard will be issued in the near future under the auspices of the North West European group of countries who have interests in offshore exploration —Belgium, Denmark, Eire, France, Netherlands, Norway, Sweden, United Kingdom and West Germany.

There is close agreement between all current standards on the most fundamental aspect of the mooring system—the mooring line strength requirement. This dictates or influences stowage space; vessel lightweight; anchor sizes; winch size, strength, power and braking; chain stoppers; fairleads and to some degree the structural strength of the hull itself.

The following factors of safety in terms of mooring line breaking strength over maximum tension are representative of the standards now being applied.

Table 1 Mooring line factors of safety

Case	Condition	Factor of Safety
1	Operating	3.0
2	Damaged Operating	2.0
3	Survival	2.0
4	Damaged Survival	1.4
5	Damaged Survival (Close proximity)	2.0

Notes
- (i) Cases 1 and 3 are for the intact mooring system.
- (ii) Damage cases 2, 4 & 5 refer to the depleted system after failure of a single mooring line.
- (iii) Case 5 is intended for vessels operating alongside other installations. The factor of safety in this case applies specifically to the lines maintaining the separation between units.

3.3 Operating Limits

In the context of mooring, the limitations which define the vessel's operational range are basically those of water depth and environmental criteria. Within these constraints the particular role of the vessel will impose additional but linked limitations, the motions of the vessel being restricted to a specified maximum in a particular weather state normally. These limitations are generally defined by the operator or designer of the unit.

3.3.1 Water Depth

Current generation semi-submersibles are commonly being designed for a water depth range in the order of 70 to 500 m. This covers for the large part offshore operations in the North Sea and on all the great continental shelves—American, African, Australian, Asian etc.

It is somewhat easier to increase the upper limit of depth than to decrease the lower one.

In *shallow water* there are two basic problems—

(i) The catenary is flatter and the system more stiff, with the consequence that relatively small vessel motions build up high line tensions.

(ii) With vessels such as drillers which require to keep station to within a percentage of the water depth (as opposed to a fixed distance), station keeping becomes increasingly difficult as the depth decreases. A driller in 40 m of water for instance would be limited to 2.0—2.5 m in total offset, an amplitude which wave surge alone could exceed in fairly moderate conditions.

The mooring system has limited influence over the first order wave motions referred to in (ii) above, but where operating is feasible the better mooring performance in shallow water comes from wire rope.

If handling the system can be accommodated, combination mooring lines of wire-chain, with chain forming the upper part of the line, offer some advantage over wire rope alone in terms of lower tensions for the same restoring force.

With regard to *deep water*, the effects of water depth on the capability of two alternative mooring systems of comparable strength, one wire rope and one chain cable, are shown in Figure 10. This particular plot is drawn for a maximum vessel offset of 5% of water depth.

The nature of the catenary system means that mooring stiffness reduces as depth increases. In deeper water cable weight exerts a more significant influence, producing a steeper catenary form which gives less restoring force within the bounds of operating tension limits. Coupled with this reduction in restoring force, higher pre-tension values are required to keep station.

The consequences for the vessel in deeper water are that (a) the higher level of working tension shortens the life of the mooring lines and (b) operations must be restricted to less severe environmental conditions. For instance a vessel capable of operating in Beaufort 9 conditions in 150 m water depth could be limited to Beaufort 6 in 500 m of water; this represents a considerable reduction in capability.

It is also apparent from Figure 10 that strength for strength wire rope is more effective than chain cable throughout the depth range. The difference is not marked in shallow water but in deeper water wire rope shows a more significant advantage in performance. At 400 m water depth for example, wire rope produces almost 60% more restoring force than chain cable with only 75% of the pre-tension.

For very deep water, and activity is increasing in ultra-deep water areas as exploration pushes out to the continental slopes and beyond, wire-chain combination lines offer a good performance. Unlike the shallow water case the chain cable should form the lower part of the mooring line. Deck machinery and handling requirements are more complex however, with this type of system.

It has to be added that there are many factors besides operating performance to be considered in selecting one material or combination against another; capital cost, equipment weight, handling and laying the system, deck machinery requirements, service life etc., have all to be evaluated.

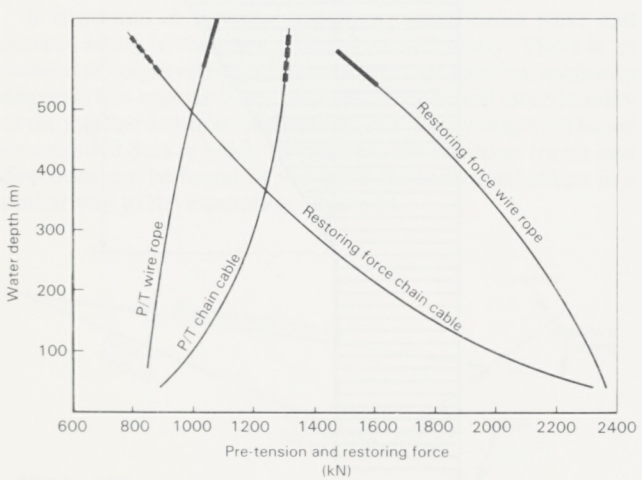


Fig. 10 Effect of water depth on pre-tension and restoring force

3.3.2 Environmental Limits

Operating

Design operating criteria are generally given in terms of environmental criteria coupled with vessel maximum allowable motions.

In practice the latter is the most meaningful limiting factor in regulating operational activities: excessive heave curtails drilling, high surge motions on an accommodation unit cause bridge disconnection, etc. The environmental criteria associated with the specified motions limit is only one particular combination of conditions chosen to define the design standard.

It is normal, however, for specific environmental conditions, wind speed or sea state, to set the criteria for change of rig draught from operating to survival.

Survival:

Survival conditions are generally represented by the 50 year or 100 year storm for the designated area of operation. The vessel will be expected to remain moored on general location in these conditions but not to necessarily maintain close-order station keeping.

The over-riding concern in these conditions is to minimise mooring line tensions and anchor loads.

Table 2 shows typical design environmental criteria for a large deep water semi-submersible driller.

3.4 Environment

3.4.1 Wind

Wind is clearly not a steady phenomena and its measured velocity in a storm will fluctuate greatly over short periods of time. Nevertheless, for mooring design purposes wind force is treated as a predominantly steady effect. This approach is justifiable at least for large vessels which will not respond significantly to short gusts but will be displaced from an original neutral position by the effect of some mean wind pressure.

Table 2 Typical design environmental criteria

CONDITION	MAXIMUM VESSEL OFFSET % WATER DEPTH	ENVIRONMENTAL LIMITS					
		WIND SPEED (m/sec)	WAVE				CURRENT SPEED (m/sec)
			SIGNIFICANT		MAXIMUM		
			HEIGHT (m)	PERIOD (secs.)	HEIGHT (m)	PERIOD (secs.)	
NORMAL DRILLING	3	12	4	7	7	9	0,5
LIMITED DRILLING	5	20	7	9,5	13	12	0,5
WAITING ON WEATHER	10	32	9	10,5	17	13,5	1,0
SURVIVAL	UNLIMITED	50	16	14	30	19	1,5

The choice of wind averaging period to represent the mean force case is a somewhat arbitrary one, but for mooring problems at least, the 1 minute mean speed referenced to a height of 10 metres above mean sea level is considered appropriate. As wind speed increases with height above sea level according to an power law, a wind profile similar to that shown in Figure 11 is required, to form the basis for correct variation of pressure and force with height. The velocity coefficients are based on a power law exponent of 0,12 as recommended by the U.K. Department of Energy for the 1 minute mean wind speed.

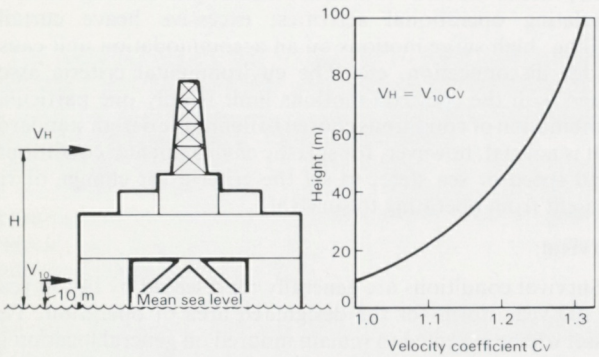


Fig. 11 Wind velocity gradient for 1 minute mean wind speed

This type of wind gradient also allows the conversion of recorded wind speeds to the standard V_{10} form.

e.g. Recorded wind speed $V_H = 35$ m/sec.
Height of anemometer above sea level = 55m

$$V_H = V_{10} C_V$$

$$V_{10} = \frac{V_H}{C_V}$$

From Figure 11, $C_y = 1.23$

$$V_{10} = \frac{35}{1.23}$$

$$= 28.5 \text{ m/s.}$$

3.4.2 Current

The design current speed is taken as the sum of tidal and wind induced currents for the relevant operating areas.

Current speed is not, however, constant over water depth. Specific and accurate velocity profiles can be established for particular areas but this is not wholly necessary for determining mooring loads on vessels with a low draught to water depth ratio, which is mostly the case in offshore locations.

For mooring design purposes tidal current speed can be taken to be constant with depth, and wind induced current can be reduced linearly with increasing depth below sea level. The total current profile can be as shown in Figure 12.

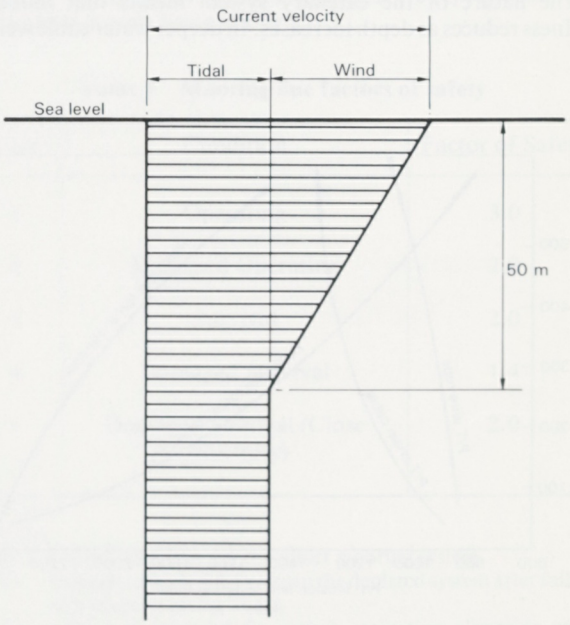


Fig. 12 Current velocity profile

3.5 Environmental Forces and Motions

3.5.1 Total Motion

Mooring line tensions and anchor loads are directly related, but not linearly, to vessel movement or offset. The highest static loads occur when the vessel is at its greatest distance from its original pre-tensioned position.

The basis for the quasi-static approach to mooring analysis is shown diagramatically in Figure 8.

Figure 13 below shows in another way the total horizontal motions of an anchored vessel in a seaway.

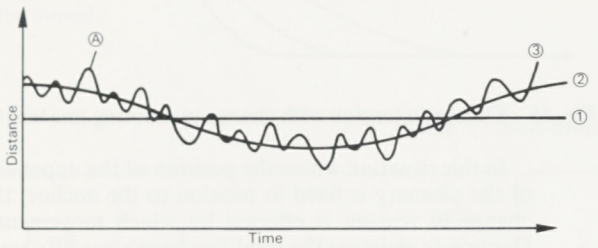


Fig. 13 Lateral Motions of anchored vessel

It can be seen that the vessel's pattern of motion comprises three separable effects:

1) a steady displacement from the origin to a new mean position, this shift being due to wind, current and mean wave drift forces:
2) a low frequency oscillation about the new mean position. This is the result of a slowly varying drift force —principally wave drift but with some wind influence;
3) surge or sway oscillations at wave frequency. These are also referred to as first order wave motions—the surge/sway amplitudes vary directly with wave amplitude.

The position of maximum vessel displacement and greatest anchor line tension in this particular cycle is marked (A).

3.5.2 Steady Drift Forces

The steady drift forces acting on a semi-submersible are in order of dominance; wind, current and mean wave drift, with wind force normally contributing some 60%—70% to the total. In areas with unusual conditions of high current, in excess of 3-4 knots, current may replace wind as the major influence. Wind and current forces vary as the velocity squared and mean wave drift force is a function of wave height squared.

It is normal to consider maximum wind forces wave and current acting in the same direction concurrently. There is an element of conservatism here but at least one national authority demands this approach. In cases where the actual directionality of the weather has to be considered, or if an investigation based on recorded data is being carried out, the resultant forces and directions can be found by vectoring the individual effects in a similar way to the example in Figure 14.

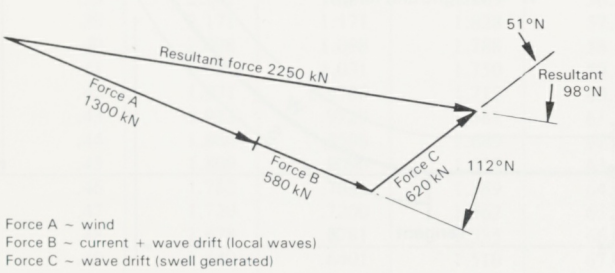


Fig. 14 Environmental force vectors

Forces are normally calculated for a number of vessel headings to establish the most severe case. With semi-submersibles, bow forces can be almost as great as beam forces. Normally the greatest total force is generated in a segment around a quartering direction.

The steady drift forces can be determined by direct calculation methods or by model testing. Suitable methods of calculation are given in Appendix A.

Wind Force:

The above water structure on a semi-submersible can be a fairly complex arrangement of discrete members and assemblies —tubular columns, diagonal bracings, scattered deckhouses, pipe racks, drilling derrick, crane jibs, etc. For this type of unit wind tunnel tests are being increasingly used to determine wind forces and moments as this is considered by many designers to offer a more refined approach than direct calculation methods, which are unable to take realistic account of shielding and interaction between members or of lift effects which introduce forces normal to the wind direction.

It has been frequently asserted that wind forces calculated by the standard IACS or IMO wind drag method are conservatively high. One particular field investigation [2] carried out on a large semi-submersible driller concluded that the actual total environmental force acting on the unit, found by analysing recorded mooring line tensions, was something like 75% of model test predictions and only 55% of calculated wind forces. Considering that the total measured force would have included a wave drift component in the direction of the wind and possibly a wind induced current in the same direction, the discrepancy between measured and calculated forces is substantial.

Other data obtained from a Lloyd's Register classed semi-submersible showed that the apparent total environmental force, again found by resolving recorded mooring line tensions, was some 50% of the force calculated by standard methods.

However, such data can be very much subject to recording and interpreting errors which could greatly affect the conclusions. Consequently, the results from a small number of field studies, although interesting, are by no means conclusive.

There are other reasons to justify some caution before discarding too readily the established calculation method. While it may well prove to be the case that actual wind forces are somewhat lower than those calculated by conventional wind drag formulae, the total design approach used to date has proved satisfactory in practice—the method of calculating forces, the static methods of determining catenary behaviour, and the factors of safety for the system. The conservatism in one area may be compensating for omission in another, slowly varying wave drift forces are not normally considered, neither are line dynamics or stress concentrations and bending losses in cables for instance.

It is possible that a change in design approach is justified but the total method and philosophy has to be considered not just one particular element.

Current and Wave Drift Forces:

For the same reason that wind tunnel testing is now commonly used to determine wind forces, tank testing is being increasingly adopted by designers to obtain current and wave drift forces. The underwater structure of a semi-submersible, unlike a mono-hull vessel, is subject to shielding and interference effects between its primary elements, twin hulls, buoyancy columns and horizontal and diagonal bracings, etc., as shown in Figure 15. The pontoons are also commonly fitted with projecting azimuthing thrust units.

All these features and their complex interactions make assessment of loads by direct calculation methods difficult and unreliable. At this time properly constituted model tests appear to offer the most satisfactory solutions.

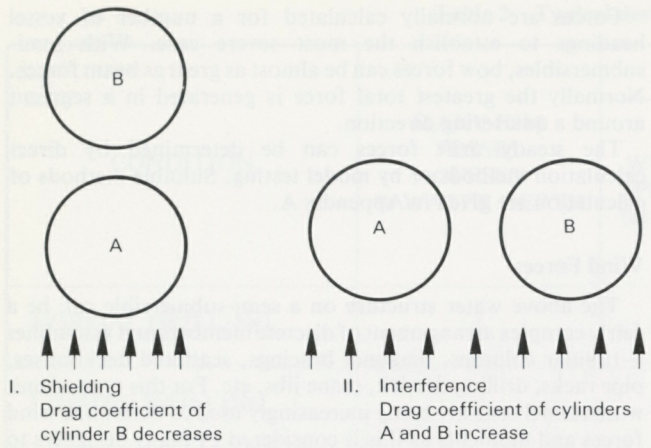


Fig. 15 Interaction between closely spaced cylinders

3.5.3 Slowly Varying Wave Drift Force

This is generated in an irregular sea and is, like the mean component of wave drift, proportional to the wave height squared. The slowly varying force is not normally considered in the static type of analysis described in this paper. It has been the belief to date that the standard factors of safety given to mooring systems designed using this type of approach are sufficiently conservative to take care of a phenomena which was not widely understood but thought to be fairly minor in effect.

More attention is now being paid to this particular aspect. While the magnitude of the force is not generally large the frequency of the oscillations, which are thought to be in phase with the frequency of higher wave groups, can in some cases coincide with the vessel's own natural frequency in surge or sway causing resonance which in turn leads to high peak loads in the system.

There are no satisfactory empirical or concise methods of calculating slow wave drift force for the semi-submersible. Drift force can be obtained by model testing in irregular waves or by computer simulation techniques and various programs have been developed for this purpose.

3.5.4 Wave Motion

First order wave effects are defined by vessel motion as an amplitude rather than by force and as mooring line tension in a catenary varies in a known way with the movement of its upper end, motions are a convenient means of simulating the effect of wave passage.

For mooring purposes surge and sway are the most relevant first order motions. They are taken to vary directly with wave height, rather than with wave height squared as for drift forces.

The motion characteristics of the vessel are generally established by tank testing, with the results given in the form of response amplitude operators which give motion amplitude per unit wave amplitude.

First order wave forces are cyclic and extremely high and it is common practice for deeper water moorings to assume that the vessels motions will not be affected or suppressed by the mooring system. On this principle, the full surge and sway amplitudes derived for a free floating vessel are generally used for mooring analysis.

3.6 Catenary System

3.6.1 Catenary Response

Having established the steady forces acting on the vessel and its motions in the wave, the response of the complete mooring system to these imposed effects has to be determined.
The basis for calculating the total response of the multi-line system is the behaviour of the single individual catenary cable when subjected to imposed load or forced motion.

Two basic aspects of catenary behaviour are of particular interest:

(i) Change in the length and form of the mooring line with variations in tension, as shown in Figure 16 below.

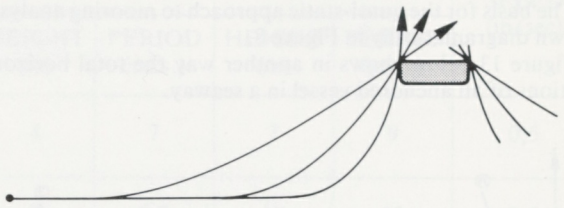


Fig. 16 Change in tension with change in mooring line length

In this situation where the position of the upper end of the catenary is fixed in relation to the anchor, the change in tension is effected by winch movements. Hauling-in shortens the total line length but lifts extra cable off the ground thereby, increasing tension; paying-out cable has the opposite effect. Pre-tensioning the mooring lines and pre-loading the anchors is carried out in this way.

(ii) Change in line tension resulting from displacement of upper end as shown in Figure 17.

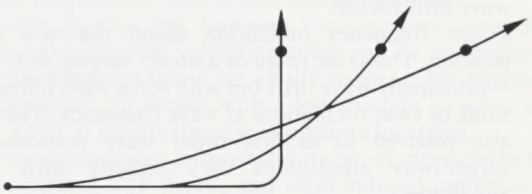


Fig. 17 Change in tension with displacement of mooring line upper end

In this case the total line length does not change other than the amount caused by elastic stretch. Tension changes are the result of forced movement of the upper end of the catenary as the vessel responds to environmental forces. The further the vessel moves from the anchor the more cable is lifted from the ground and the higher the line tension becomes.

The following catenary equations define the most important of the relationships between line tension, weight and geometry. Refering to Figure 18, we can see that,

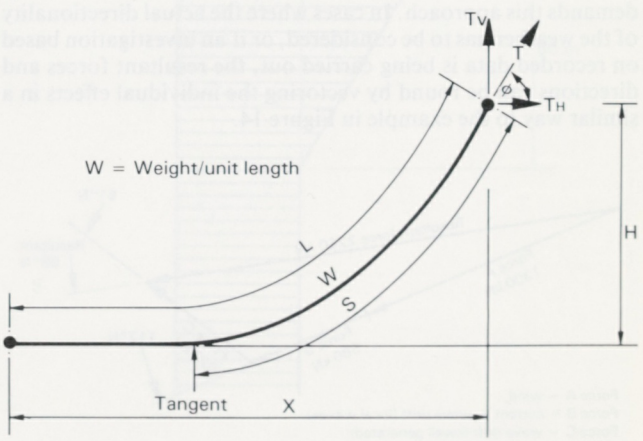


Fig. 18 Catenary diagram

$$X - L = \frac{T_H}{W} \operatorname{arccosh}\left[1 + \frac{WH}{T_H}\right] - \sqrt{H\left[H + \frac{2T_H}{W}\right]} \quad (1)$$

$$S = \sqrt{H\left[\frac{2T}{W} - H\right]} \quad (2)$$

$$T = T_H + WH \quad (3)$$

$$T_V = S\,W \quad (4)$$

From the behaviour of a single cable, how far it will move when load is applied and how much load it will pick up when moved, the overall response of a multiple line system can be determined.

3.6.2 Calculation Methods

Small scale mooring problems involving single or low numbers of mooring lines and load cases can be satisfactorily solved by hand calculation methods using catenary equations of the form given in the foregoing section.

Table 3 gives a convenient alternative to the use of the basic equations. This type of format [3] gives the principal catenary relationships in the form of non-dimensional coefficients valid for catenaries in the range between completely slack and tensioned to just short of producing a vertical force at the anchor.

Table 3 Non-dimensional catenary relationships

$\frac{L-x}{H}$	$\frac{T}{WH}$	$\frac{T_H}{WH}$	$\frac{\frac{T_V}{WH}}{\frac{S}{H}}$	Φ	$\frac{L-x}{H}$	$\frac{T}{WH}$	$\frac{T_H}{WH}$	$\frac{\frac{T_V}{WH}}{\frac{S}{H}}$	Φ
.01	2223	2222	66.67	1.719	.51	1.570	0.5702	1.463	68.71
.02	556.3	555.3	33.34	3.436	.52	1.538	.5382	1.441	69.52
.03	247.6	246.6	22.23	5.151	.53	1.508	.5082	1.420	70.31
.04	139.6	138.6	16.68	6.862	.54	1.480	.4800	1.400	71.08
.05	89.61	88.61	13.35	8.567	.55	1.454	.4536	1.381	71.82
.06	62.44	61.44	11.13	10.27	.56	1.428	.4278	1.362	72.56
.07	46.05	45.05	9.545	11.96	.57	1.404	.4045	1.345	73.26
.08	35.42	34.42	8.357	13.65	.58	1.382	.3818	1.328	73.96
.09	28.13	27.13	7.434	15.32	.59	1.359	.3594	1.311	74.67
.10	22.92	21.92	6.696	16.99	.60	1.340	.3398	1.296	75.31
.11	19.07	18.07	6.094	18.64	.61	1.321	.3205	1.281	75.96
.12	16.14	15.14	5.593	20.27	.62	1.303	.3026	1.267	76.57
.13	13.85	12.85	5.167	21.91	.63	1.285	.2850	1.253	77.19
.14	12.04	11.04	4.804	23.52	.64	1.268	.2676	1.239	77.82
.15	10.58	9.580	4.490	25.11	.65	1.253	.2528	1.227	78.36
.16	9.383	8.383	4.215	26.69	.66	1.238	.2381	1.215	78.91
.17	8.392	7.392	3.973	28.26	.67	1.224	.2236	1.203	79.47
.18	7.561	6.561	3.758	29.80	.68	1.210	.2104	1.192	79.99
.19	6.858	5.858	3.566	31.33	.69	1.197	.1974	1.181	80.51
.20	6.256	5.256	3.393	32.84	.70	1.185	.1845	1.170	81.04
.21	5.742	4.742	3.238	34.33	.71	1.173	.1728	1.160	81.53
.22	5.296	4.296	3.097	35.79	.72	1.162	.1624	1.151	81.97
.23	4.905	3.905	2.968	37.24	.73	1.151	.1509	1.141	82.47
.24	4.561	3.561	2.850	38.67	.74	1.141	.1407	1.132	82.92
.25	4.259	3.259	2.742	40.07	.75	1.132	.1317	1.124	83.32
.26	3.990	2.990	2.642	41.46	.76	1.123	.1227	1.116	83.73
.27	3.754	2.754	2.551	42.81	.77	1.114	.1138	1.108	84.14
.28	3.538	2.538	2.465	44.16	.78	1.105	.1050	1.100	84.55
.29	3.346	2.346	2.386	45.48	.79	1.097	.0973	1.093	84.91
.30	3.175	2.175	2.313	46.76	.80	1.090	.0897	1.086	85.28
.31	3.018	2.018	2.244	48.04	.81	1.082	.0821	1.079	85.65
.32	2.876	1.876	2.180	49.29	.82	1.076	.0757	1.073	85.97
.33	2.747	1.747	2.120	50.51	.83	1.069	.0692	1.067	86.29
.34	2.630	1.630	2.064	51.70	.84	1.063	.0628	1.061	86.61
.35	2.522	1.522	2.011	52.88	.85	1.056	.0565	1.055	86.93
.36	2.423	1.423	1.961	54.04	.86	1.051	.0512	1.050	87.21
.37	2.332	1.332	1.914	55.17	.87	1.046	.0460	1.045	87.48
.38	2.247	1.247	1.869	56.27	.88	1.041	.0408	1.040	87.76
.39	2.171	1.171	1.828	57.36	.89	1.036	.0356	1.035	88.03
.40	2.098	1.098	1.788	58.44	.90	1.031	.0315	1.031	88.25
.41	2.031	1.031	1.750	59.49	.91	1.027	.0274	1.027	88.47
.42	1.971	0.9706	1.715	60.49	.92	1.023	.0233	1.023	88.69
.43	1.913	.9129	1.681	61.50	.93	1.019	.0191	1.019	88.93
.44	1.860	.8596	1.649	62.47	.94	1.015	.0151	1.015	89.15
.45	1.809	.8090	1.618	63.44	.95	1.012	.0121	1.012	89.31
.46	1.762	.7625	1.589	64.36	.96	1.009	.0090	1.009	89.49
.47	1.720	.7200	1.562	65.25	.97	1.006	.0060	1.006	89.66
.48	1.678	.6781	1.535	66.16	.98	1.004	.0040	1.004	89.77
.49	1.640	.6401	1.510	67.03	.99	1.002	.0020	1.002	89.89
.50	1.604	.6041	1.486	67.88	1.00	1.000	0.0000	1.000	90.00

Knowing any one parameter the others can be read from the table. For example to find horizontal distance "x" from anchor to vessel fairlead.

Known parameters are as follows:

Mooring line length	L = 1150 m
Mooring line weight in water	W = 1.1 kN/m
Pre-tension	T = 1230 kN
Water depth	H = 250 m

$$\frac{T}{WH} = \frac{1230}{1.1 \times 250} = 4.473$$

From Table, $\frac{L - x}{H} = 0.243$ (by interpolation)

$$x = L - (0.243\ H)$$
$$= 1150 - (0.243 \times 250)$$
$$= \underline{\underline{1089\ m}}$$

The effect on line tension of subsequent vessel motion represented by a change in the dimension 'x' can now be readily determined.

For example,

From vessel surge, movement of fairlead = 5 m

$$\text{New 'x' value} = (1089 + 5) = 1094\ m$$

$$\frac{L - x}{H} = \frac{1150 - 1094}{250} = 0.224$$

From Table, $\frac{T}{WH} = 5.14$ (by interpolation)

$$T = (5.14 \times 1.1 \times 250)\ kN$$
$$= \underline{\underline{1413.5\ kN}}$$

A common calculation approach used to establish a response range for a system comprising a number of lines is to move the total mooring system incrementally from its origin, calculating new line tensions for each line at each offset step. The sum of the vectored tensions represents the restoring force at that point, as seen in Figure 19. The new distances from anchors to fairleads are found at each offset step by standard geometry and used to calculate the changes in tension.

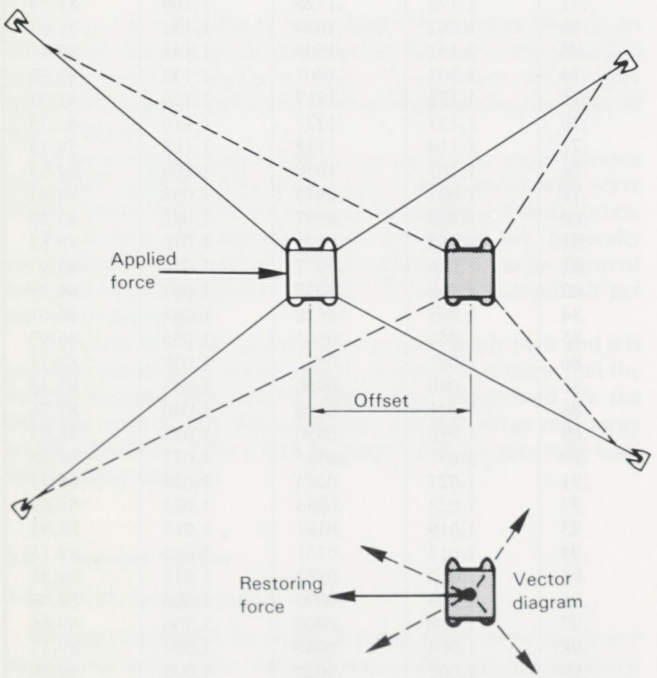


Fig. 19 Vectoring tensions to obtain restoring force

This calculation can be done for different directions of motion corresponding to the vessel moving in response to bow, beam or quartering weather, etc. The results plotted in the form of restoring force and high-line tension curves, can then be used to establish line tensions for specific cases of vessel steady force and motion.

An example of this type of plot and the method of obtaining peak line tension from imposed force and motion is shown in Figure 20.

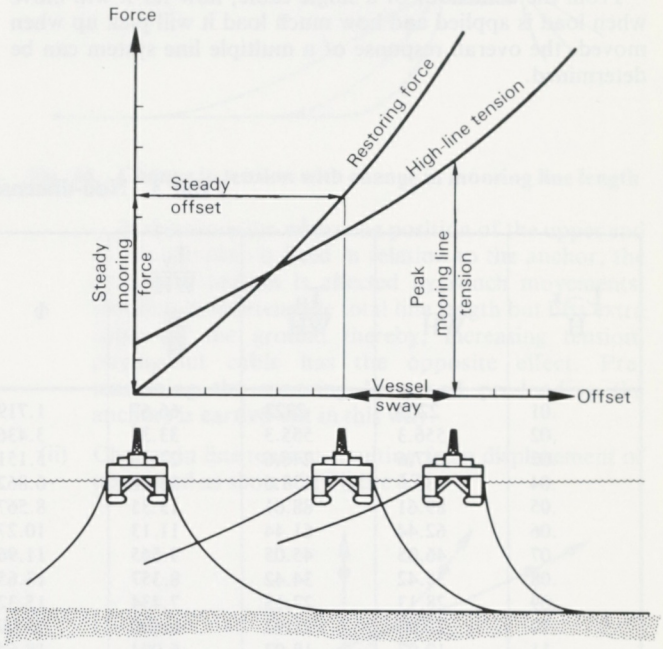


Fig. 20 Typical curves of force and tension against vessel offset

Investigation of the catenary behaviour of most positional mooring systems with their multiple mooring lines and high number of different loading cases, water depths and directions of motion can only reasonably be carried out by computer. This is particularly so when refinements such as elastic stretch of mooring lines, combination wire-chain lines, sea-bed friction effects, yawing moments, line breakage and resulting transient motion, etc., have to be considered.

This latter effect, transient motion, is of particular importance in the case of accommodation units and crane barges, etc., which work alongside fixed platforms. Following a mooring line breakage the sudden loss of restraint and release of stored energy cause the vessel to oscillate in the horizontal plane until such time as the motions are damped out and a new settled position is found where the remaining mooring lines statically balance the environmental force as seen in Figure 21. It is, therefore, necessary to establish the envelope of motion bounded by the transient path of the vessel so that;

(a) sufficient physical clearance will be maintained between the installations in event of this type of accident occuring;

(b) line tensions at the extremity of motion are within allowable limits.

A desk-top computer program has been developed in the Ocean Engineering Department incorporating the various features and refinements referred to above. This program is specifically intended for positional mooring system analysis to current standards, but the format allows any conventional single or multi-line catenary system to be evaluated.

Sample output from the program, entitled SPREAD, is given in Appendix B.

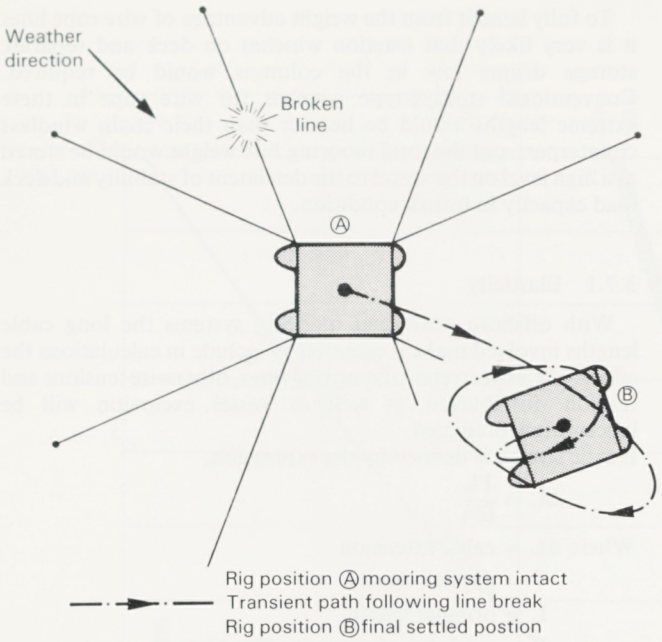


Fig. 21 Transient motion following mooring line failure

3.7 Mooring Line Data

The information given in this section is the type of basic data on mooring lines essential for mooring system evaluation.

Breaking Strength:

The values given by Figure 22 are minimum rated breaking strengths. There is always a margin over and above this rated value before actual ultimate failure, frequently over 10%, but this is never assumed or taken advantage of in calculations. The basis for the minimum rated values are as follows:

(i) Chain Cable grades U2, U3, Oil Rig Quality and Grade 4

Break test load = $K\,d^2\,(44 - .08d)$ kgf.

where d = chain cable diameter (mm)

K = 1.4 (U2)
2.0 (U3)
2.15 (Oil Rig Quality)
2.8 (Grade 4)

(ii) Wire Rope

Standards for the sizes and types of wire ropes used for offshore mooring are not unified in the same way as chain cable.

The breaking strength values given in Figure 22 are included primarily to show the general relationship of wire rope to chain cable and are based on one particular commercial make of wire rope.

Weight in Air and Water:

Weight in water is required for catenary calculations and weight in air for stowed on-board mass. Figure 23 illustrates the relevant data.

Minimum Line Length:

Figures 24 and 25 give the minimum lengths needed outboard of the suspension point on the vessel, normally the lower fairlead, to prevent any uplift force at the anchor. Lengths are given for two different tension cases; 50% of the rated minimum breaking strength where this is the maximum permitted line tension and 70% of the rated breaking strength as allowed in some cases following a single line failure. These are nett lengths and to obtain actual functional line length, additions have to be made where appropriate for the following:

(a) Distance from lower fairlead to storage drum or chain locker;
(b) Length lost to drag when setting anchors;
(c) Pre-tensioning mooring lines;
(d) Allowance to permit manœuvering and movement to stand-off position;
(e) Allowance for line slackening in heavy weather.

Not all these allowances are applicable in every instance and in some cases one allowance will cover more than one contingency.

If the minimum line lengths are looked at in terms of scope, the ratio of line length to water depth, it is clear that the figure of 10 often quoted as a desirable minimum for anchoring is only applicable in shallow water. A scope of only 2 is required for the same chain cable in deep water. Wire rope minimum scope needs to be around 20 in shallow water and 4 in deep water.

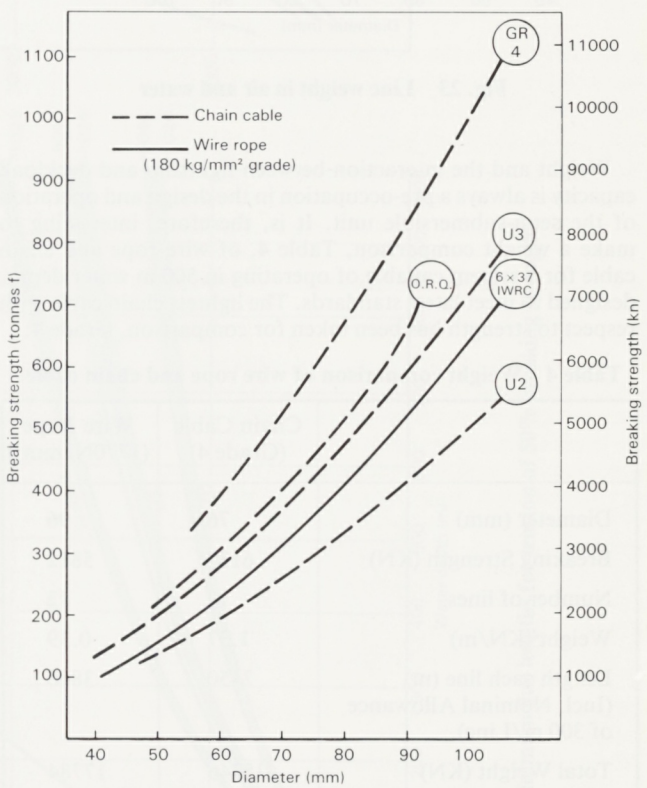


Fig. 22 Line breaking strength

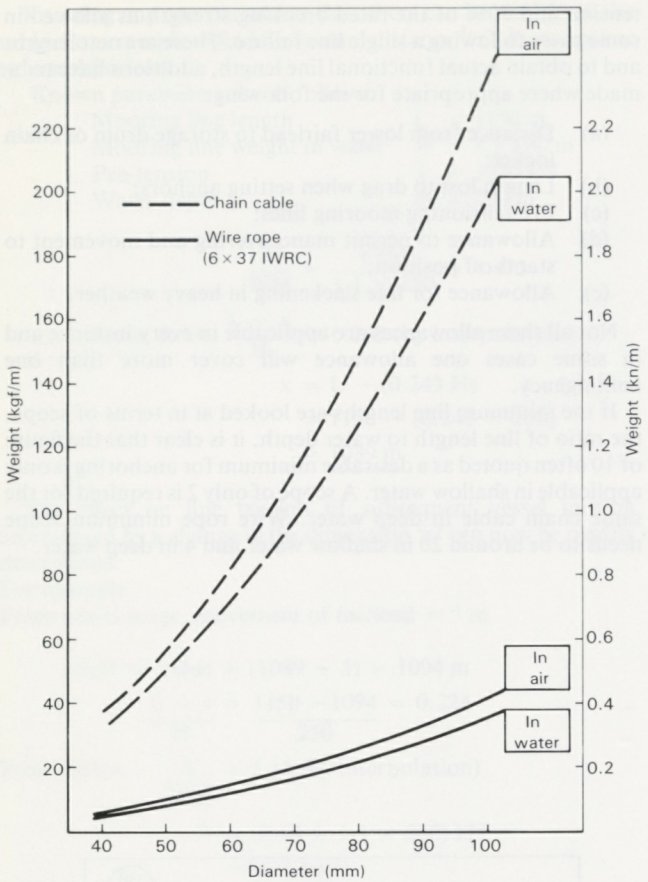


Fig. 23 Line weight in air and water

Weight and the interaction between lightship and deckload capacity is always a pre-occupation in the design and operation of the semi-submersible unit. It is, therefore, interesting to make a weight comparison, Table 4, of wire rope and chain cable for a system capable of operating in 500 m water depth, designed to meet latest standards. The lightest chain cable with respect to strength has been taken for comparison, Grade 4.

Table 4 Weight comparison of wire rope and chain cable.

	Chain Cable (Grade 4)	Wire Rope (1770N/mm²)
Diameter (mm)	76	96
Breaking Strength (KN)	6130	5812
Number of lines	12	12
Weight (KN/m)	1.37	0.39
Length each line (m) (Incl. Nominal Allowance of 300 m/Line).	2150	3800
Total Weight (KN)	35346	17784
Mass (Tonnes)	3603	1813

The result of this comparison shows that wire rope mooring lines would be little more than half the weight of equivalent strength chain cable. Expressed in another way, chain cable would contribute almost 1800 tonnes more to the lightship weight than wire rope.

To fully benefit from the weight advantage of wire rope lines it is very likely that traction winches on deck and separate storage drums low in the columns would be required. Conventional storage-type winches for wire rope in these extreme lengths would be heavier than their chain windlass counterpart and the total mooring line weight would be stored at a high level on the vessel to the detriment of stability and deck load capacity in transit condition.

3.7.1 Elasticity

With offshore positional mooring systems the long cable lengths involved make it essential to include in calculations the effects of elastic stretch of mooring lines, otherwise tensions and tension distribution as well as vessel excursion will be inaccurately predicted.
Elastic stretch is defined by the expression,

$$\Delta L = \frac{TL}{EA}$$

Where ΔL = cable extension
T = applied tension
L = original length
E = modulus of elasticity (See Note 1)
A = cross sectional area of cable (See Note 2)

Notes: (1) The following values of elastic modulus can be used for calculation purposes

Chain cable:
$E = 10.1 \times 10^{10}\ N/m^2$
This is appropriate for all grades of stud link chain cable.

Wire rope:
$E = 6.9 \times 10^{10}\ N/m^2$
This is valid for the most common rope used in offshore mooring—
6 × 37 construction with I.W.R.C. and applies to a bedded rope where the inelastic post-construction stretch has been taken up.

(2) The "E" values given above both relate to a notional area calculated from the nominal cable diameter.
e.g. For 76 diameter cable (wire rope *or* chain cable):

$$A = \frac{\pi}{4} \times 76^2 \times 10^{-6}$$

$$= 4.54 \times 10^{-3} m^2$$

From the values of "E" given in Note 1, it can be seen that size for size wire rope is in the order of 50% more elastic than chain cable.

When the comparative lengths of wire rope and chain cable are taken into account, Figures 24 and 25, the difference in actual stretch is even more marked. By way of comparison, in a system designed for 400 m water depth, a chain cable line will extend 7 m when loaded to half its breaking strength while a wire rope of equivalent strength, not diameter, will stretch 16 m. With respect to control and limitation of tension, higher elasticity is generally an asset; stretching absorbs some of the kinetic energy of vessel motion which would otherwise have to be dissipated by lifting cable off the ground and increasing tensions.

Where station keeping is the primary concern, high elasticity can be less desirable for obvious reasons.

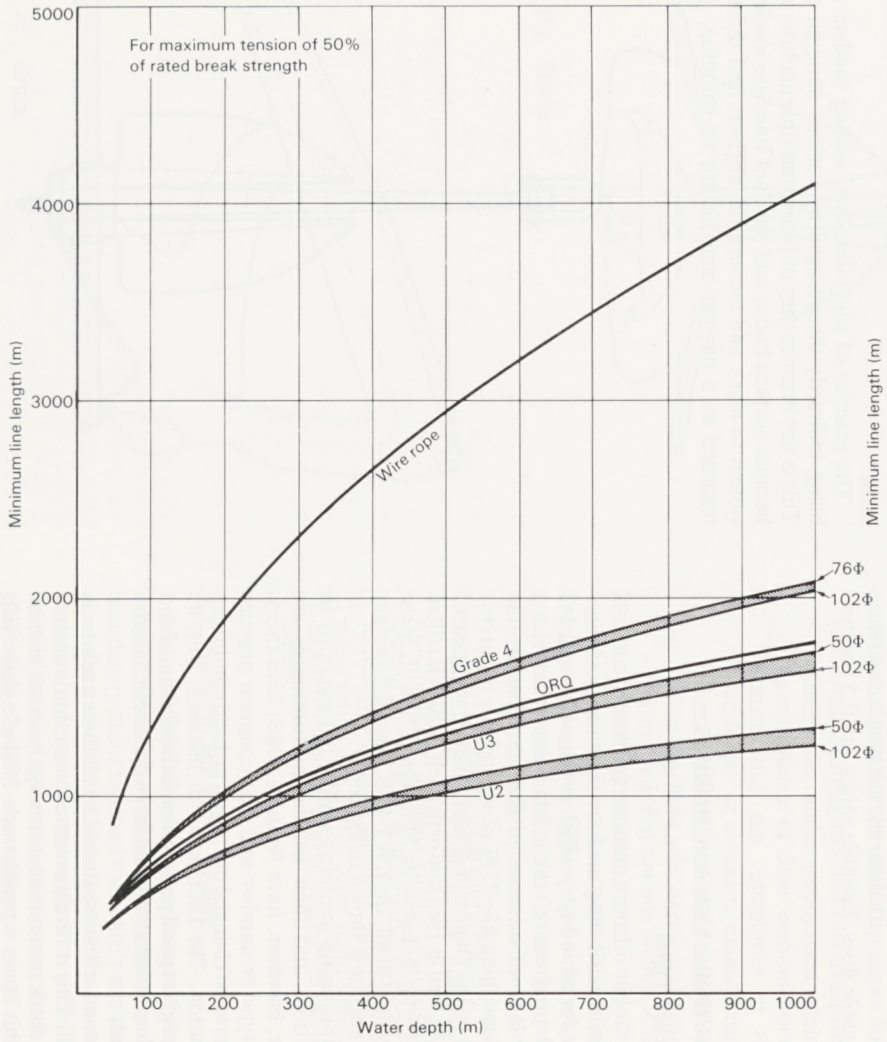


Fig. 24 Minimum line lengths for tension of 50% breaking strength

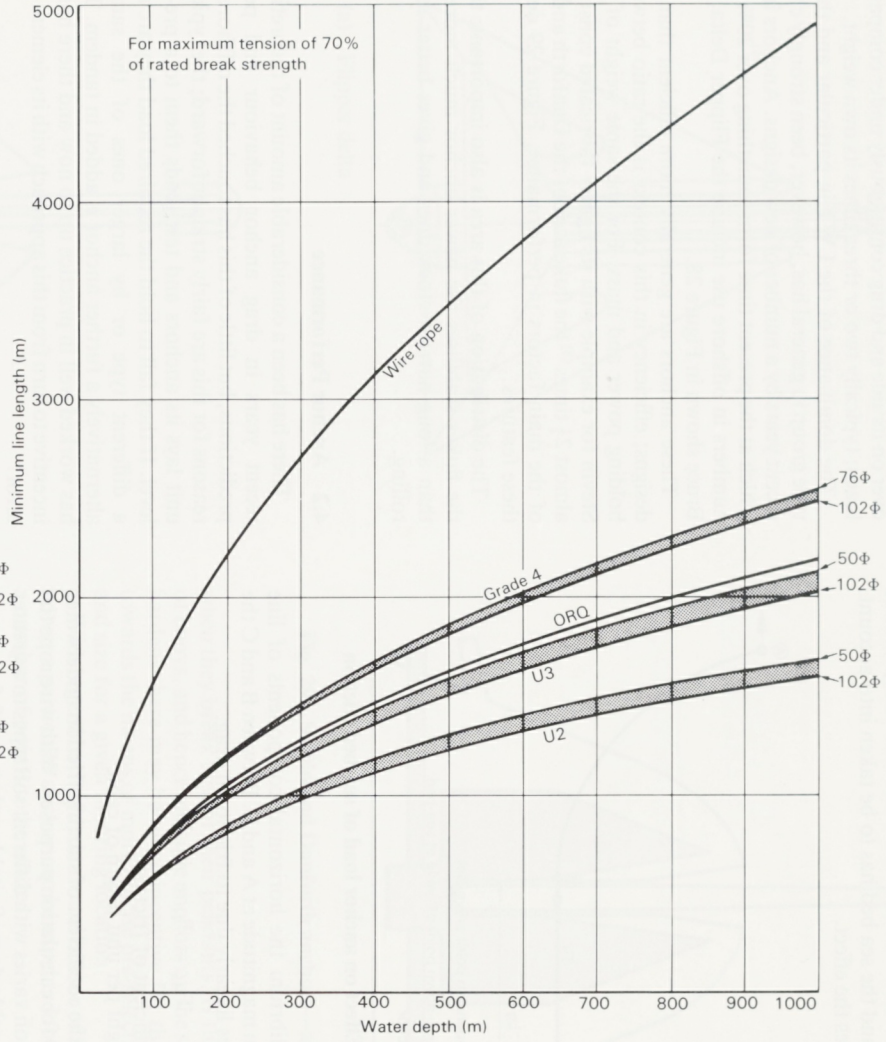


Fig. 25 Minimum line lengths for tension of 70% breaking strength

3.7.2 Sea-bed Friction

If anchor loads and elastic stretch of mooring lines are to be correctly evaluated the effect of friction between the grounded part of the cable and the sea bed has to be taken into account. Figure 26 illustrates the effect.

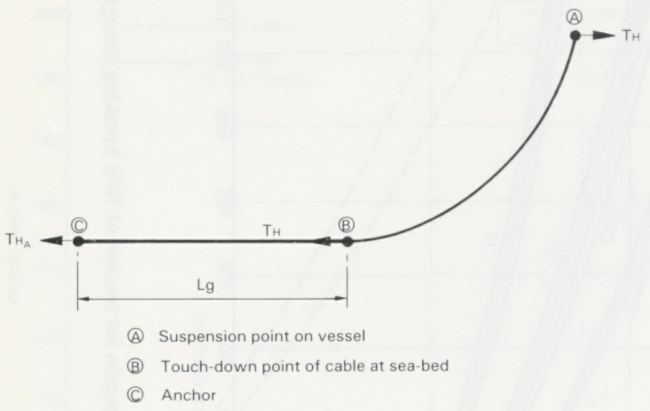


Fig. 26 Effect on anchor load of sea-bed friction

For static equilibrium the horizontal components of line tension are equal in magnitude at A and B. Between B and C the line tension reduces linearly due to frictional drag.

$$T_{H_A} = T_H - \mu L_G W$$

where μ = coefficient of friction
W = weight per unit length of cable

For chain cable the coefficient of starting friction underwater can be taken as 1.0 for calculation purposes. With wire rope the coefficient of friction varies with different soil types to a greater extent than chain cable does. Suitable values are 0.5 for mud and 1.0 for sand.

4. ANCHORS AND ANCHORING

4.1 Offshore Anchor Types

The majority of mobile offshore units use fairly conventional high holding power marine drag anchors for their positional mooring. However for an industry which is generally regarded as innovative and progressive, there has been a surprising conservatism and lack of advance in the actual anchoring equipment used. Something like 75% of all anchors in current use are types based on the Danforth design which first appeared over 40 years ago. As well as the Danforth itself, which is still in common use, this group includes the Moorfast, Offdrill, Stato and the most widely used of all, the LWT-U.S. Navy lightweight design. This latter anchor is shown in Figure 27.

The anchors in this group are fairly similar to each other in shape and proportions and their general performances are comparable. Some, however, have features which lend themselves to one soil type or another and it is common practice offshore for anchors to be changed out to suit ground conditions at a particular location. The Danforth, for instance, with its sharp pointed flukes gives good penetration in hard ground and the Stato with its blunter but somewhat large fluke area, is more effective in soft mud.

An important common feature shared by all these anchors is the transverse stock. This is rarely seen now on a ship's anchor mainly because the stock prevents neat stowage in a shell anchor recess. However, this is not a problem on offshore units with their protruding external anchor racks. The presence of a stock greatly improves performance by giving the anchor the stability it needs to dig-in initially and to help maintain its proper attitude while under load. A standard stockless anchor with its fairly closely spaced flukes and lacking a stabilising bar can roll over on its side and drag continuously under comparatively low loads; typically two or three times its own weight.

The dominance of the LWT in particular and the Danforth type group in general has, however, been strongly challenged in recent years by a number of new designs. Anchors in this group which at the present time form something over 20% of the total numbers in offshore use include the Flipper Delta, Stevin and Bruce shown in Figure 28.

These anchors are generally more efficient than the earlier designs; efficiency in this context is the ratio between anchor holding power and mass. For the same weight of anchor the Stevin for example with its lighter fabricated construction has almost $2\frac{1}{2}$ times [8] the fluke area of the Danforth and area is one of the main factors in performance. Figure 29 demonstrates these features.

The distribution of this area is also important; the width of the flukes stabilises the newer anchor much more effectively than a long narrow stock does and gives better resistance to rolling.

4.2 Anchor Performance

There has been a considerable amount of theoretical work in recent years in drag anchor behaviour and performance predictions, but little of this has touched the offshore scene. The reasons for this are fairly straight forward; the typical offshore unit lays its anchors and test loads them to a pre-designated level. If they fail to hold the required load they are replaced by a different type or by larger ones of the same type or alternatively a further anchor is added in tandem. This system has worked well in practice up to now and there has been little incentive to turn from this approach with its element of trial and error.

The practice of piggy-backing, adding tandem anchors, is being indirectly discouraged by various national authorities. This is not because they object to multiple anchors as such, but because surface buoys and pendant lines are needed with this system to mark and retrieve the anchors and these buoys are regarded as a navigational hazard to shipping, particularly

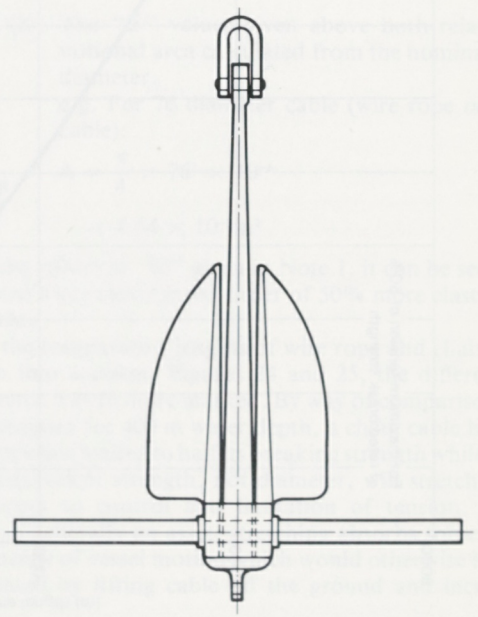
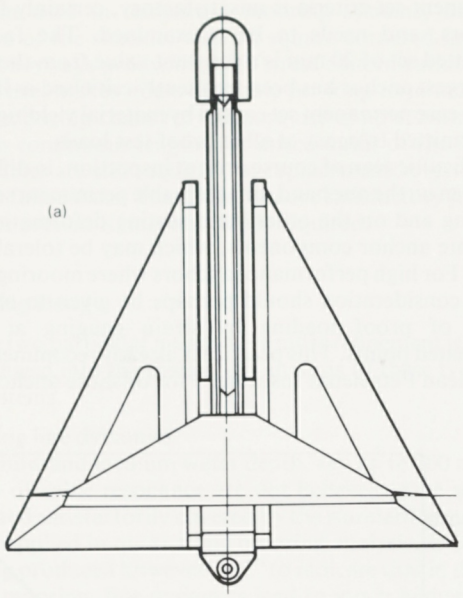
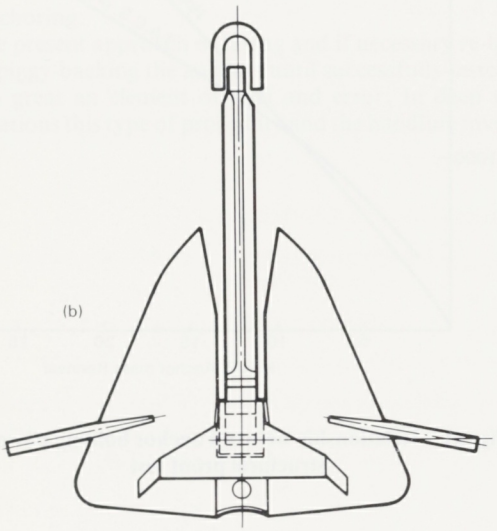


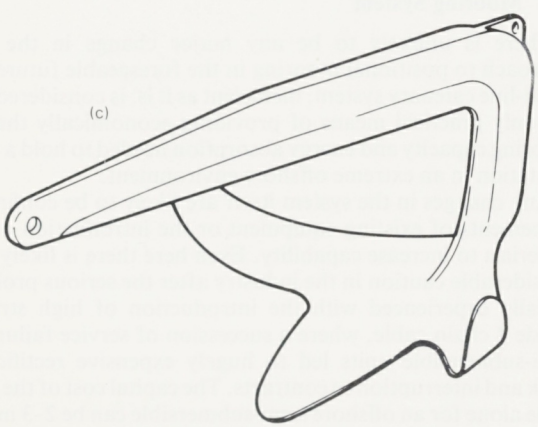
Fig. 27 U.S. Navy lightweight anchor



(a) Flipper delta



(b) Stevin



(c) Bruce

Fig. 28 Modern high holding power anchors

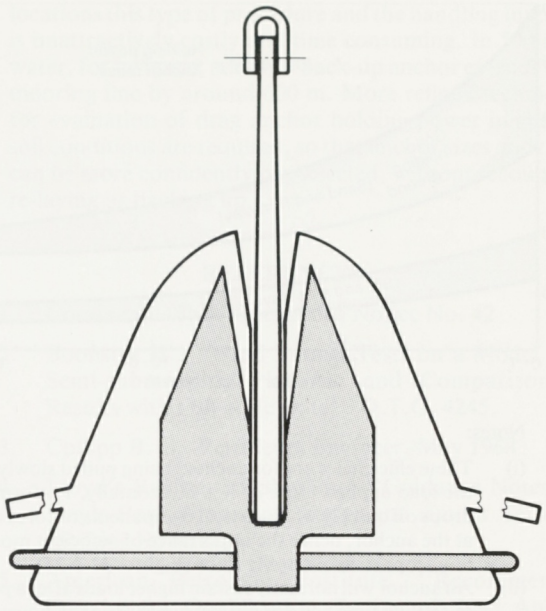


Fig. 29 Stevin and Danforth anchors—area comparison

when they break free of their pendants. If this discouragement of buoys, and hence multiple anchors on the same mooring line, hardens there may be more incentive for the industry to turn towards the means of more precise pre-selection of anchor type and size for a given mooring location.

With regard to the fundamental matter of how much holding power a particular anchor can be expected to develop, there are a number of points to be made:

(i) Anchor designers and manufacturers almost without exception make extravagent claims regarding the performance of their own anchors while frequently downrating the capabilities of their competitors' products. In essence, manufacturers' promotional literature is not a reliable basis for anchor selection;

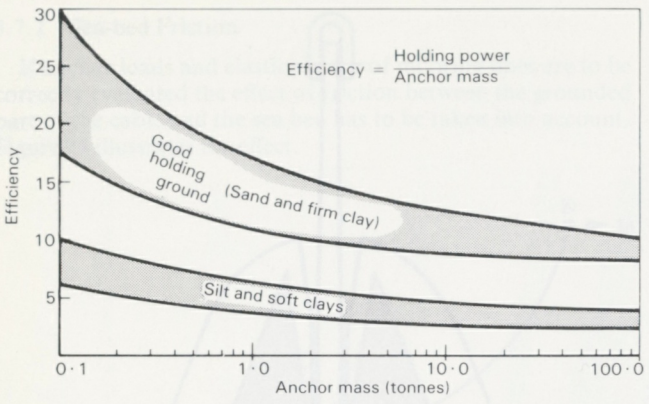
(ii) some anchors are decidedly better than others in certain soils but not one anchor is superior in all types of holding ground;

(iii) some anchors claim high efficiencies. But this has been achieved by lightening at the expense of structural strength with the result that they cannot achieve their potential holding power without suffering damage.

Figure 30, taken from the references,[4] gives scatter bands of efficiencies into which the majority of current high holding power offshore anchors can be expected to fall. This should be taken as general guidance only. On the one hand narrowly specialist anchors can improve significantly on these values and on the other hand some areas of the North Sea defy most anchors to reach even the lower limit of these bands.

4.3 Strength and Proof Testing

Many of the common anchors used offshore are identical or adapted versions of ship high holding power anchors. The mandatory proof test load for a ship's anchor is laid down in the Anchors and Chain Cable Rules 1970 for a British registered vessel and in classification rules. This proof test load is directly related to the anchor's own mass and according to the philosophy behind the sizing of ships' temporary mooring equipment, it is a load which would not normally be exceeded before anchor drag occurs.



Notes:

(i) These efficiencies are for anchors being pulled slowly with the load applied more or less horizontally. Performance drops off quickly when vertical components of force occur at the anchor, hence the importance of sufficient mooring line scope to avoid uplift force (Figures 24 & 25).

(ii) An anchor will normally sustain higher loads after a period of settling time has elapsed, say upwards of 24 hours, and the soil has consolidated. It will also take higher dynamic loads than steady loads mainly due to the effect of negative pore pressure at the back of the flukes. How much gain depends on the soil type but up to $2\frac{1}{2}$ times steady pull load is possible.

(iii) The efficiency of individual anchors is not maintained in a piggy-back arrangement—the combined holding power will only be in the order of 75% of the sum of individual anchor capacities.

Fig. 30 High holding power anchor efficiency

Anchors, especially the more modern lightweight ones, are frequently designed structurally on the basis of the tabular proof test load in asssociation with stresses close to material yield.

It has to be recognised that an anchor designed and tested on this basis only may not be suitable for positional mooring purposes. The reason for this can be seen in Figure 31 where class (I.A.C.S.) proof test loads and notional anchor holding power under steady pull are plotted against H.H.P. anchor mass.

It is plain from this graph that with anchors of 9000 kg and above the potential holding power exceeds the structural proof test and the gap widens with increasing size. Even allowing for the fact that the standard method of proof testing, virtually a point load applied to the flukes, is arguably more severe than normal service loading, the discrepancy between structural strength and potential loading, a gap of 30% with an anchor of 25000 kg mass, cannot be ignored. It is, therefore, important that for positional mooring anchors the design is checked and approved for the maximum mooring load which will have been established as part of the mooring analysis by direct calculation and, furthermore, that the anchor is adequately proof tested. There is some merit in the approach of one national authority which requires an anchor to be proof tested to half the breaking strength of its attached mooring line; the maximum load which the anchor should see with the system intact. This particular approach has not found much favour with anchor manufacturers, removing as it does the convenience of the traditional testing and certification process where only the anchor's own mass was relevant.

The present classification acceptance criteria for an anchor after proof test, is visual inspection for freedom from significant defect and maximum permanent set of 20 mm between fluke and crown shackle. In the author's opinion the permanent set criteria is unsatisfactory, certainly for offshore anchors, and needs to be re-examined. The fact that the permitted set of 20 mm is a constant value from the smallest to the largest anchor has been frequently criticised as illogical and in any case permanent set caused by material yielding should not be permitted to occur at all at proof test loads.

Difficulties can of course arise at inspection, in differentiating between on the one hand, unacceptable permanent set caused by yielding and on the other hand seating deformation between separate anchor components, which may be tolerable in some cases. For high performance anchors where mooring integrity is vital, consideration should perhaps be given to checking the effect of proof loading by strain gauging at important designated points. This practice is already recommended by the American Petroleum Institute [5] for offshore anchors.

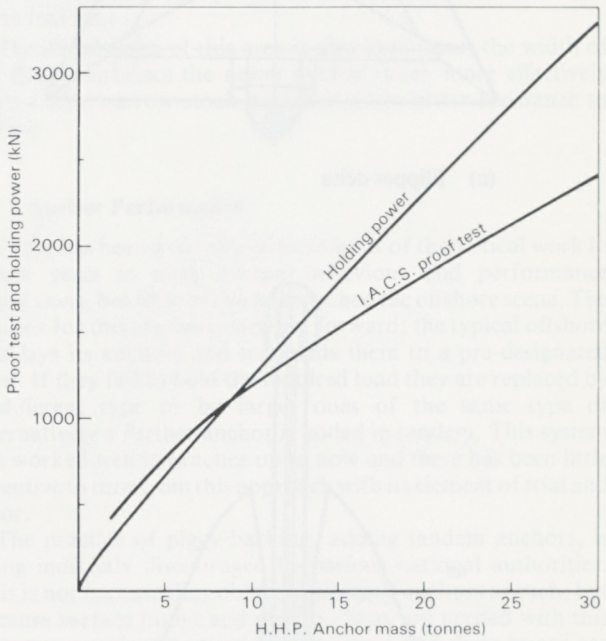


Fig. 31 Relationship between anchor holding power and structural proof test

5. CONCLUDING REMARKS

5.1 Mooring System

There is unlikely to be any major change in the basic approach to positional mooring in the foreseeable future. The multi-line catenary system, inefficient as it is, is considered to be the only practical means of providing economically the high mooring capacity and energy absorption needed to hold a vessel on station in an extreme offshore environment.

Any changes in the system itself are likely to be confined to refinements of existing equipment or the introduction of new materials to increase capability. Even here there is likely to be considerable caution in the industry after the serious problems initially experienced with the introduction of high strength Grade 4 chain cable, where a succession of service failures on semi-submersible units led to hugely expensive rectification work and interruption to contracts. The capital cost of the chain cable alone for an offshore semi-submersible can be 2–3 million pounds and the day rates for a driller £40,000–£50,000.

One particular item of equipment where improvement and innovation is required is the chain cable joining shackle. The present Kenter shackle has a fairly satisfactory performance

record when used in temporary mooring systems, but the construction of the shackle, with its square cornered internal rebates and keyways producing high stress concentrations and low fatigue life, makes it less desirable for long-term mooring use. While mooring chain for offshore use is now commonly produced in continuous lengths for initial outfit of the vessel, joining shackles are still required for replacement in service of damaged or failed links. Therefore, a more satisfactory joining link than the present Kenter shackle is required.

5.2 Mooring Design

There are two particular areas where more refinement is likely to be introduced into the design and analysis of these types of mooring systems.

(a) Mooring line dynamics:
In shallow and medium water depth, say up to 300 m, the effects of cable resonance are not believed to be significant, and satisfactorily covered by the standard factors of safety applied in quasi-static mooring analysis. Evidence is being produced however, [6], [7] to indicate that in deeper water mooring, line dynamics lead to much higher peak tensions than that implied by the static shift of vessel/mooring line upper end. More attention is likely to be given to this aspect in future.

(b) Anchoring:
The present approach of laying and if necessary re-laying or piggy-backing the anchors until successfully tested has too great an element of trial and error. In deep water locations this type of procedure and the handling involved is unattractively costly and time consuming. In 500 m of water, for instance, adding a back-up anchor extends each mooring line by around 600 m. More refined techniques for evaluation of drag anchor holding power in specific soil conditions are required, so that anchor sizes and types can be more confidently pre-selected, without recourse to re-laying or backing up.

6. REFERENCES

1. Continental Shelf Operations Notice No. 42
2. Boonstra H., "Wind Tunnel Tests on a Model of a Semi-submersible Platform and Comparison of Results with Full-scale Data". O.T.C. 4245.
3. Collipp B. G., Petroleum Engineer, May 1968.
4. Lloyd's Register of Shipping, "Guidance Notes for Single Point Moorings, Buoys and similar Tethered Floating Structures".
5. American Petroleum Institute, "Recommended Practice for Qualification Testing of Steel Anchor Designs for Floating Structures". API RP 2M.
6. Ormberg H., Fylling I. J., Morch M., "Dynamic Response in Anchor Lines: Numerical Simulations Compared With Field Measurements". O.T.C. 4497.
7. Larsen C. M., Fylling I. J., "Dynamic Behaviour of Anchor Lines".
8. Vryhof Ankers B.V., Brochure.

APPENDIX A

ENVIRONMENTAL FORCES

1. Wind Force

The following adaption of the standard wind drag equation can be used to calculate wind force. Total wind force is obtained by calculating and summing the forces on individual elements of the structure each of which can be assigned a representative shape and height coefficient.

$$F_W = K A V^2 C_H C_S$$

where F = Wind force (N)

K = 0,613

A = Projected area of element normal to wind direction (m^2)

V = Wind velocity (m/sec)

C_H = Height coefficient (see Table A.1)

C_S = Shape (drag) coefficient (see Table A.2).

This method is taken from the version given in the Rules for Mobile Offshore Units except that the height coefficients given in Table A.1. have been adapted to give the velocity profile for the one minute mean wind speed used in mooring calculations.

Table A.1 Height coefficients for the one minute mean wind speed condition

HEIGHT ABOVE SEA LEVEL (m)	HEIGHT COEFFICIENT C_H
0 — 10	1.00
15	1.10
20	1.18
25	1.25
30	1.30
35	1.35
40	1.39
45	1.43
50	1.47
55	1.51
60	1.54
65	1.57
70	1.60
75	1.62
80	1.65
85	1.67
90	1.69
95	1.72
100	1.74

Table A.2 Shape coefficients

SHAPE	C_S
Spherical	0.4
Cylindrical	0.5
Large flat surface (hull, deckhouse, smooth under deck area)	1.0
Drilling derrick	1.25
Wire ropes	1.2
Exposed beams & girders under deck	1.3
Small parts	1.4
Isolated shapes (crane, beam, etc.)	1.5
Clustered deckhouses or similar	1.1

In calculating wind force by this method the following points are relevant:

(i) In the case of units with columns, the projected areas of all columns should be included; i.e., no shielding allowance should be taken.

(ii) The block projected area of clustered deck houses may be used in lieu of calculating each individual area. The shape coefficient may be assumed to be 1.1.

(iii) Isolated houses, structural shapes, cranes, etc., should be calculated individually, using the appropriate shape coefficient.

(iv) Open truss work commonly used for derrick towers, booms and certain types of masts may be approximated by taking 30% of the projected block area of each side, (e.g., 60% of the projected block area of one side for double-sided truss work). An appropriate shape coefficient is to be taken from the table.

2. Current Force

When calculating current force only form or pressure drag need be considered: frictional resistance makes a comparatively small contribution to the total drag force and can generally be neglected. The following can be used to estimate current force

$$F_C = 512.5 A V^2 C_d$$

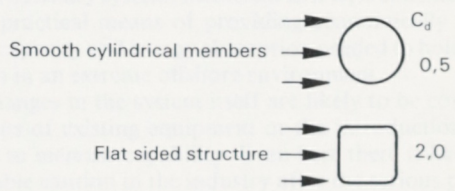
where F_C = Current force (N)

A = Projected area of underwater element normal to flow direction (m^2)

V = Current velocity (m/sec)

C_d = Drag coefficient

Drag coefficients should be derived from test or experimental sources, but where these are not available the following values can be used to calculate approximate forces.



APPENDIX B

Extracts from Lloyd's Register's Static Mooring Program SPREAD

Figure B.1 is input information; the geometry of the mooring spread, the mooring line physical properties and the initial setting-up tensions.

Figure B.2 gives the results, in terms of new vessel position and revised line tensions, of applying a steady environmental force in a quartering direction.

Figure B.3 indicates the consequences of breakage of one line, number 5 in this case, on the static shift of vessel position and the re-distribution of mooring line tensions and anchor loads.

Figure B.4 shows the plot of transient vessel motion in time steps of 5 seconds following the loss of line number 5.

In this particular case the vessel overshoots its ultimate settled position by over 30 m and develops a peak transient tension of almost 70% of the cable break strength. This would be acceptable for the accident case.

Fig. B1

MOORING CONFIGURATION DATA RETRIEVED FROM DATA FILENAME : SPRD10

UNITS : LENGTH IN METRES , FORCE/WEIGHT IN KN & MASS IN TONNES

TOTAL LINE LENGTH ,L = 1500 METRES

ATTACHMENT POINT HEIGHT ,H = 400 METRES

FRICTION COEFF. BETWEEN LINE & BOTTOM ,Mu = 1

LINE WEIGHT / METRES ,Wc = 1.47 KN

EFFECTIVE LINE E-MODULUS ,E = 101000000 KN/METRES^2

ASSOCIATED LINE CROSS-SECTIONAL AREA ,A = .0059 METRES^2

LINE BREAKING STRENGTH = 7700 KN

YAW MOMENT TOLERANCE = 100000 KN - METRES

INITIAL MOORING LINE CONFIGURATION

VESSEL C. of G. X = 0.0 Y = 0.0 Z = 400.0

LINE	Tbh	X	Y	H	ALPHA	L	EA	Wc
1	200.0	50.0	-35.0	400.0	22.5	1500.0	5.95900E+05	1.47000E+00
2	200.0	50.0	-35.0	400.0	67.5	1500.0	5.95900E+05	1.47000E+00
3	500.0	-50.0	-35.0	400.0	112.5	1500.0	5.95900E+05	1.47000E+00
4	1500.0	-50.0	-35.0	400.0	157.5	1500.0	5.95900E+05	1.47000E+00
5	820.0	-50.0	35.0	400.0	202.5	1500.0	5.95900E+05	1.47000E+00
6	770.0	-50.0	35.0	400.0	247.5	1500.0	5.95900E+05	1.47000E+00
7	1500.0	50.0	35.0	400.0	292.5	1500.0	5.95900E+05	1.47000E+00
8	500.0	50.0	35.0	400.0	337.5	1500.0	5.95900E+05	1.47000E+00

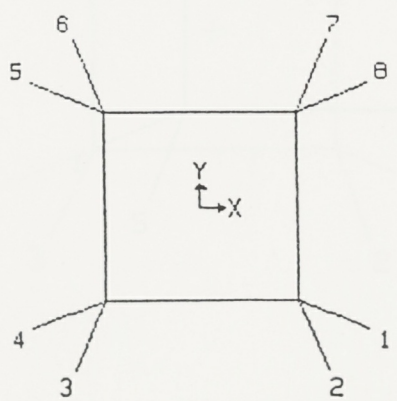


Fig. B2

APPLIED ENVIRONMENTAL FORCE = 4.90000E+03 KN
IN THE DIRECTION = 45.00 DEGREES
AND YAW MOMENT = 2.50000E+04 KN-METRES

POSITION RELATIVE TO INITIAL EQUILIBRIUM CONFIGURATION

OFFSET = 52.41 METRES DIRECTION = 46.39 deg ROTATION = -3.75 deg

POSITION RELATIVE TO LAST EQUILIBRIUM CONFIGURATION

OFFSET = 52.41 METRES DIRECTION = 46.39 deg ROTATION = -3.75 deg

RESTORING FORCE = 4.89812E+03 KN
IN THE DIRECTION = 225.0 DEGREES
AND YAW MOMENT = -2.48373E+04 KN-METRES

LINE	TB	TBH	EXCUR	S	TAH	TAV	THETA	FOS
1	682.8	94.8	1211.84	460.00	0.0	0.0	0.0	11.28
2	686.2	98.2	1213.93	461.98	0.0	0.0	0.0	11.22
3	950.1	362.1	1301.81	597.53	0.0	0.0	0.0	8.10
4	2832.9	2244.9	1412.59	1175.47	1767.9	0.0	0.0	2.72
5	2470.7	1882.7	1403.74	1088.38	1277.6	0.0	0.0	3.12
6	2465.8	1877.8	1403.60	1087.18	1271.0	0.0	0.0	3.12
7	2790.1	2202.1	1411.64	1165.50	1710.4	0.0	0.0	2.76
8	977.9	389.9	1306.95	610.05	0.0	0.0	0.0	7.87

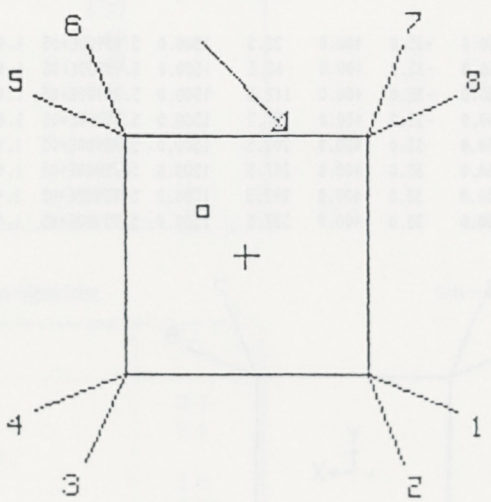


Fig. B3

APPLIED ENVIRONMENTAL FORCE = 4.90000E+03 KN
IN THE DIRECTION = 45.00 DEGREES
AND YAW MOMENT = 2.50000E+04 KN-METRES

POSITION RELATIVE TO INITIAL EQUILIBRIUM CONFIGURATION

OFFSET = 82.59 METRES DIRECTION = 38.17 deg ROTATION = 2.49 deg

POSITION RELATIVE TO LAST EQUILIBRIUM CONFIGURATION

OFFSET = 31.62 METRES DIRECTION = 24.44 deg ROTATION = 6.23 deg

RESTORING FORCE = 4.90292E+03 KN
IN THE DIRECTION = 225.0 DEGREES
AND YAW MOMENT = -2.52373E+04 KN-METRES

LINE	TB	TBH	EXCUR	S	TAH	TAV	THETA	FOS
1	642.6	54.6	1181.77	435.57	0.0	0.0	0.0	11.98
2	649.4	61.4	1187.64	439.78	0.0	0.0	0.0	11.86
3	970.1	382.1	1305.55	606.58	0.0	0.0	0.0	7.94
4	4086.5	3498.5	1433.38	1436.64	3405.3	0.0	0.0	1.88
6	3416.2	2828.2	1423.66	1303.51	2539.3	0.0	0.0	2.25
7	3091.8	2503.8	1417.89	1233.94	2112.7	0.0	0.0	2.49
8	874.0	286.0	1285.28	561.80	0.0	0.0	0.0	8.81

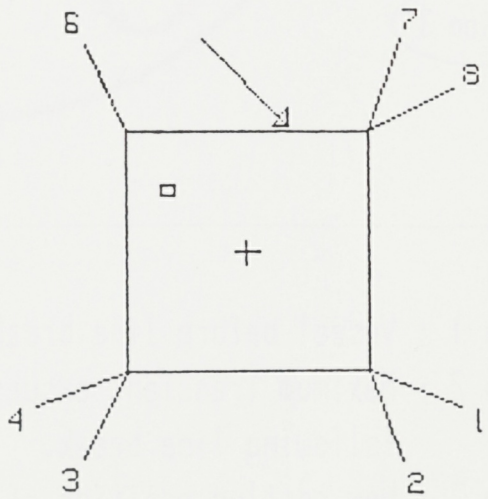
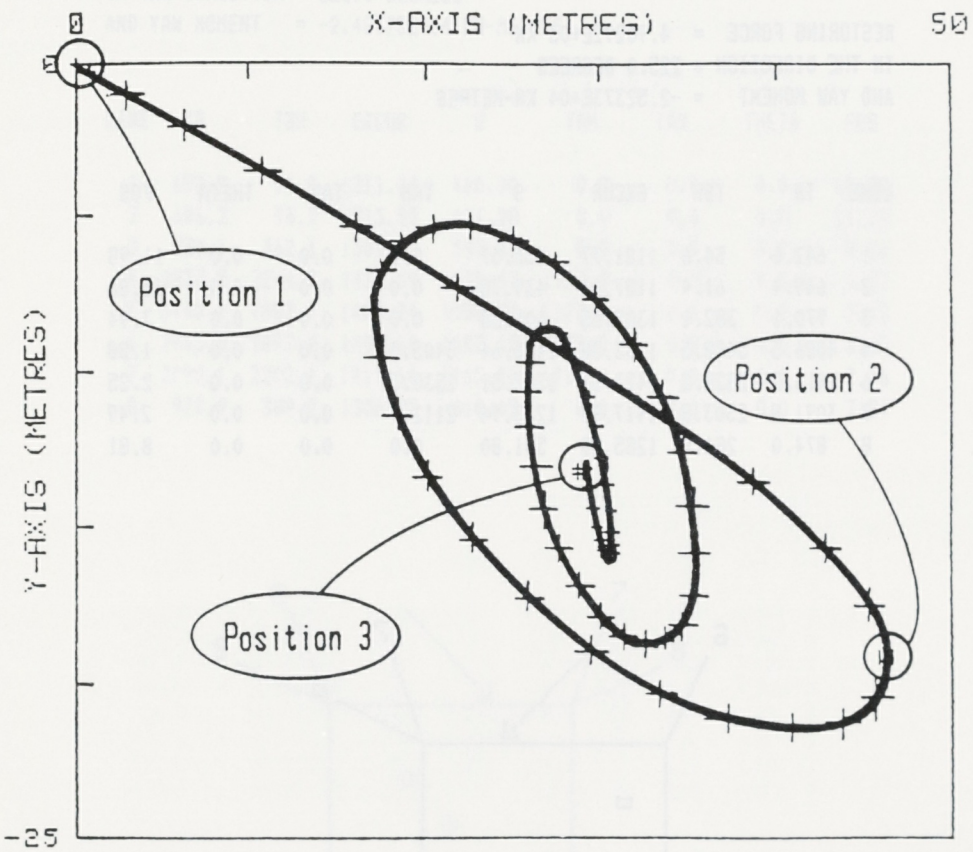


Fig. B4

DETAILS OF TRANSIENT MOTION

MAX. IN-LINE CABLE TENSION = 5551.68 KN
FOR LINE No. 4
AT TIME = 60.00 secs

SCALED PLOT OF TRANSIENT MOTION



Position 1 : Vessel before line break.
Position 2 : Maximum transient excursion following line break.
Position 3 : New settled position of vessel following line break.

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Discussion

on the paper

POSITIONAL MOORING OFFSHORE

by

R. C. Macdonald

Paper No. 4. Session 1984–85

Any opinions expressed and statements made in this Discussion Paper are those of the individuals.

Hon. Sec. C. M. Magill
71 Fenchurch Street, London, EC3M 4BS

Discussion on the Paper

POSITIONAL MOORING OFFSHORE

by

R. C. Macdonald

DISCUSSION

From Mr. G. Alford:

First of all, I must congratulate Mr. Macdonald on his paper which explains very clearly how the station-keeping of these vessels is accomplished. I am sure that Mr. Macdonald's efforts have produced a paper which will be of great value to Surveyors dealing with these systems.

The subject of positional mooring is comparatively new when it is considered that the first semi-submersibles only came into service around 25 years ago. At that time, drilling in water depths of 50 metres was considered quite an achievement. Modern vessels however, can drill in very deep waters and are capable of mooring in even the most hostile areas. Although the techniques and theories are still based on the traditional catenary system, over the years however, the mooring equipment has been up-rated and refined to cope with the greater loadings encountered in service.

It is appropriate that Mr. Macdonald's paper has been published at a time when the Society's involvement with moorings is increasing. National Authorities such as the Department of Energy now require that the Certifying Authorities approve the positional moorings of vessels operating in the North Sea. There is also increased demand for floating production and off-loading systems to work marginal fields where it would not be economical to install the traditional fixed platform. A large number of these floating designs use catenary moorings for position-keeping.

Although the paper has outlined the working practices and a design basis for these systems, it is now the intention to introduce requirements for positional mooring in the new *Rules and Regulations for the Classification of Mobile Offshore Units.*

Once again, Mr. Macdonald is to be thanked for all the hard work that has gone into producing his paper. I would now appreciate his comments on the following point which came to my notice when reading it. With regard to Fig. 10, which shows a comparison between wires and chain cables, it would appear that the performance of cable is somewhat less than that of wire ropes. Why then do operators use cable to the extent that they do, bearing in mind also the number of problems encountered with chains in service?

From Mr. P. J. Mills:

The author is to be congratulated on producing a most readable and informative paper. There are, however, two points on which I would be grateful for further clarification:

(a) Will the intended future positional mooring system class requirements be mandatory or optional?

(b) Is the author aware of any incident in which the loss of mooring lines seriously jeopardised platform safety?

From Captain P. Edmondson:

I would like to ask Mr. Macdonald the following questions:

(a) In paragraph 3.3.1 of the paper it states that "...where operating is feasible the better mooring performance in shallow water comes from wire rope.". I would be interested to know how much of the mooring performance, if any, relates to the easier handling qualities of wire rope as compared with the more difficult ones experienced when using chain. I would also be interested to learn whether wire rope lying on the sea bed assists in maintaining the position of the unit in a manner similar to chain cable, or is it better.

(b) In paragraph 3.5 of the paper it is noted that environmental forces relate to wind, current, wave drift (local waves) and wave drift (swell generated). Could you please advise me whether any consideration is given to rise and fall of tide, particularly in shallow water where such range of tide could influence offset.

(c) Inspection of wire rope and of chain cable would appear to consist of an extended inspection which includes in the case of wire rope a measurement of the rope's diameter. From my own experience the external appearance of wire rope gives very little indication of its internal condition and with this in mind I would be pleased to know whether these methods have proved satisfactory.

From Mr. B. Rapo:

Perhaps it may be appropriate to remind ourselves at this stage that ship mooring as opposed to positional mooring is in fact shallow water mooring and as such has evolved over long periods of time. This may explain the fact that the weight of chain cables per hawse pipe exceed the weight of anchor by factor of 4 to 5 (grade U3 chains) and even more for other grades. Why? The main reason is the need in these conditions, where the scope of the chain will typically be about 5–10, to increase the drag components of the anchor and thus make it "bite" as early as possible.

This was one of the reasons why when approached to accept positional mooring based on heavier anchors but relatively much lighter steel wire (though of adequate strength), we have rejected the proposals. Another reason worth mentioning is that excursions of the vessel moored on steel wire should be further increased on account of greater elasticity and therefore may require the ship's master to make appropriate allowances which may not always be possible in crowded anchorage situations.

From Mr. D. R. Prentice:

It was brought to my attention recently, in a design specification for a semi-submersible production platform, that there was a requirement for provision to be made whereby the mooring lines could be released instantaneously.

Would the author please inform us about the situations which could be envisaged when this would be necessary, and the methods that could be used to effect this. By the latter I mean that from my understanding of arrangements of ships, the chain cables are attached inside the chain locker. So, do the lines have to be cut somehow on a semi-submersible or can they be released, not being so attached for example?

From Mr. D. McConnell:

I would like to thank Mr. Macdonald for an interesting and informative paper which I enjoyed very much.

I have two questions which I would like to put to the author:

(a) Mr. Macdonald mentioned in his presentation that mooring line loads experienced by semi-submersibles at operating draught are similar for both longitudinal and transverse weather directions. However, I would be interested to learn if operators make any attempt to position such units in a manner which will minimise the mooring line loads, bearing in mind the prevailing weather directions?

(b) Has the author encountered the situation where nylon mooring lines have been introduced to the mooring system to "soften" mooring line loads, especially snatch loads, or to distribute more evenly the reaction loads to the moored vehicle itself?

From Mr. J. Crawford:

Mr. Macdonald is to be congratulated on his presentation of a very interesting paper. The paper was, of course, basically referring to the mooring patterns and requirements in relation to offshore installations. However, little if any information was given as to the securing arrangements in way of the installation. In this respect whilst details of the mooring arrangements are not required for classification purposes, details of the mooring winches are required to be submitted for appraisal in relation to certification aspects. Having regard to the essential nature of the mooring system in respect to positioning and indeed safety of the unit, it is considered that such items of equipment should also be required to be appraised for classification purposes. It would be of interest to know the author's view on this point.

On one of the slides presented, requirements for the testing of mooring cables (wire rope) were indicated. Having regard to the construction of such cables could the author give some indication of results of examination by X-ray of such a mooring cable.

AUTHOR'S REPLY

First let me express my thanks to all colleagues who attended the presentation of the paper, or who made a contribution to this discussion. The interest is appreciated.

To Mr. G. Alford:

Mr. Alford is correct in saying that chain cable is less effective than wire rope in terms of mooring performance. Wire rope offers more restoring force for less pre-tension than cable does throughout the water depth range covered in Fig. 10, and the advantage increases with water depth.

The basic reason for the superior mooring performance of wire rope is its lesser weight per unit length, being only 20–25% of the weight of equivalent strength stud link chain cable. And this of course points to the other advantage of wire rope—weight saving, and the additional deck load capacity which this saving permits.

There are also however certain disadvantages with wire rope. These are two of the principal ones.

(a) Consequences of damage.
Localised damage to wire rope can cause the premature retirement of an entire anchor line, which can be upwards of 2000 metres long and 60–90 mm diameter. The same degree of local wear or damage with chain cable can be rectified by the individual substitution of comparatively inexpensive connecting links.

(b) Winch Control
Wire rope mooring systems using conventional storage drum winches suffer the disadvantage of a decline in brake capacity and motor pull, as rope layers build up on the drum and increase the torque from line pull. While these winches should ideally be working on one layer of wire rope (and this is commonly the winch design assumption) this cannot often be achieved in practice, to the detriment of mooring line control and tension adjustment. This contrasts unfavourably with chain cable windlasses with their constant radius gypsies which regularise applied torques, and maintain consistent brake/motor performance.

In fact the choice between wire rope and chain cable anchor lines offshore is, in practice, very dependent on vessel type and on the particular operating function of the unit.

Pipelay barges and crane barges for instance which have to lay and pick-up moorings frequently, almost always use wire rope, which is lighter and consequently needs less handling vessel assistance. Drillers on the other hand which moor on location for 3–6 months duration tend to favour chain cable for its robust qualities (and sometimes because it is erroneously considered to be more effective in mooring terms).

Current figures for the percentages of vessels of different type, using chain cable, wire rope or combination chain/wire for positional mooring are as follows.

VESSEL TYPE	TOTAL No. OF VESSELS INCLUDED	% OF VESSELS USING:		
		CHAIN CABLE	WIRE ROPE	COMBINATION
DRILLING UNITS (SEMI-SUBMERSIBLE)	176	72	22	6
†DRILLSHIPS	62	24	37	19
WORK UNITS (SEMI-SUBMERSIBLE)	30	37	63	—
†WORK UNITS (SINGLE-HULL)	165	—	81	—
†ALL UNITS	433	35	49	6

†Dynamically positioned vessels make the totals up to 100% in these categories

To Mr. P. J. Mills:

The proposed Rule amendments will offer positional mooring as an optional class item. Compliance would entitle the vessel to have the special features notation PM.

On the matter of mooring line failures and platform safety, as a certifying authority for the U.K. Department of Energy we receive reports of various problems and failures which have occurred in U.K. waters. These can involve vessels outwith our direct involvement.

There have been a number of chain cable failures reported on accommodation units for example. Mooring failures are particularly unwelcome with this type of vessel, operating as they do alongside fixed platforms. These failures have generally occurred at low loads, basically as result of inherent faults in the chain cables, rather than from high line tensions, so post-failure vessel movement has tended to be small with no damaging collisions involved.

While these particular incidents have not had serious consequences, their occurrence has reinforced the case for mooring analysis including the effects of line breakage on,

(a) vessel movement, to avoid subsequent collisions, and
(b) on other line tensions to prevent successive failures.

To Captain P. Edmondson:

While wire rope is somewhat easier to handle than chain cable, the mooring performance mentioned in 3.3.1 refers primarily to the capacity of the total system to resist mooring load within allowable motion and tension limits. This statement was made in the context of a spread mooring system with properly pre-tensioned lines, and would not be applicable for instance to a ship free-dropping an anchor and cable. Here chain cable weight is a great advantage.

On the second part of the question, length for length wire rope lying on the sea-bed is less effective in mooring restraint than chain cable. The holding power of grounded cable is a function of its weight and its coefficient of sea-bed friction. Chain cable is 4–5 times heavier than wire rope and its coefficient of friction in mud (for example) is twice that of wire rope. So in that type of anchoring ground chain cable gives eight or ten times more holding power than wire rope does per unit length. This difference becomes largely irrelevant however in extreme conditions, when with maximum tensions applied virtually all the anchor line—wire or chain—will be raised from the sea-bed and cable resistance will effectively be zero.

On the question of tidal range (and heave motion due to waves) this should be considered in mooring calculations for shallow water locations—say under 50 metres. Changes in catenary height in lesser water depths can have a significant effect on line tensions and vessel motions.

Regarding inspection of cables, I agree that the satisfactory external condition of a wire rope is not always a reliable indicator of total rope soundness, but at the present time there is no requirement for anything other than visual inspection. While these methods (which can include limited internal inspection such as indicated in ISO 4309) appear to have been satisfactory to date, there is increasing interest amongst owners and authorities in the various methods being developed for more accurate non-destructive examination of wire rope by electro-magnetic means etc. My reply to Mr. Crawford also refers to this subject.

To Mr. B. Rapo:

Mr. Rapo's comments are noted and fully endorsed.

Temporary mooring or ship mooring is a shallow water moderate environment activity, and entirely different in aim and philosophy from deep water positional mooring.

To Mr. D. R. Prentice:

Quick release of anchor lines is necessary in certain emergency situations. The occurrence of a well blow-out for instance or a fire on an adjacent installation, would require a vessel to evacuate the area quickly.

While the entire cable can be run out and slipped or parted inboard at the clench this is not a particularly satisfactory or controlled method of releasing multiple anchor lines in an emergency. There are various specially designed devices now available for remote and instantaneous release of anchor lines including these:

(a) a re-useable, sea bed installed unit parted by acoustic signal.
(b) a special chain cable link incorporated in the submerged anchor line and broken by acoustically activated explosive charge.
(c) a device fitted to each stability column which physically and instantaneously cuts the chain cable.

With all these methods, a greater or lesser part of the vessels anchoring system is left behind on the sea-bed. This can generally be recovered later by grappling.

To Mr. D. McConnell:

Offshore units are headed and moored in the most favourable direction in relation to known dominant weather whenever possible. Drillers in particular operating as isolated units would choose their heading to minimise mooring loads, but not all vessels are able to adopt this practice. The moored orientation of heavy-lift crane barges and accommodation units for example can be dictated by the alignment and needs of the fixed installation which they are servicing. In these cases vessels may require to moor with the possibility of the maximum environment approaching from the least favourable direction.

On the question of reducing snatch loads, there has been no attempt, to my knowledge, to introduce nylon into anchor lines used for positional mooring. I agree that a reduction in peak mooring line loads could be achieved by the insertion into the lines of lengths of highly extensible material like nylon.

More often than not however vessel movement offshore has to be restricted by the mooring system to specific maxima, so there is a practical upper limit to the amount of energy absorption which can be achieved, at least by means of linear extension.

I would also personally doubt the ability of nylon or similar materials to stand up to offshore service of this type, although ropes made from another man-made material, Kevlar aramid fibre, are considered to be practical possibilities for a number of offshore functions including main anchor lines.

To Mr. J. Crawford:

Mr. Crawford correctly states that positional mooring systems as such are not part of classification at present, and that there is no requirement for design appraisal of the equipment. It would be desirable in my view for the primary items of equipment for this function such as winches, windlasses, fairleads and chainstoppers to be subject to design appraisal for compliance with a set standard. Future Rule amendments may have to address this point.

So far as the vessel's parent structure is concerned it is already a requirement of class that structure in way of the main equipments which form part of the positional mooring system is to meet a specific minimum strength standard (Part 3, Chapter 3, Section 3 of the *Rules and Regulations for the Classification of Mobile Offshore Units* refers).

Regarding non-destructive examination of wire rope, I have no results available from specific tests, but one commercial device measures disturbance in a rope's electro-magnetic field and equates the magnetic anomalies to loss of component wires or change in metallic area. The manufacturers claim a loss of metallic area as small as 0.5% can be detected by this technique.

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FIRE SAFETY ASPECTS OF THE 1981 AMENDMENTS TO SOLAS 1974

D. J. Holland and C. M. Magill

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Written contributions to the discussion of this paper are invited from members of the Lloyd's Register Technical Association. To ensure inclusion in the discussion paper, the contributions should be received by the Hon. Secretary in London not later than the 3rd June, 1985.

Hon. Sec. J. S. Carlton
71 Fenchurch Street, London, EC3M 4BS

FIRE SAFETY ASPECTS OF THE 1981 AMENDMENTS TO SOLAS 1974

by

D. J. Holland and C. M. Magill

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INTRODUCTION

It is just over ten years since Mr Coggon presented the last paper on this subject to L.R.T.A. The Convention for the Safety of Life at Sea (SOLAS) then in force was SOLAS '60 and the Society's Rules for fire protection, detection and extinction were contained in Chapter F in the old bound format.

In the intervening years another International Convention has come into force, SOLAS '74, and just a few months ago the 1981 Amendments to SOLAS '74 entered into force on the 1st September 1984. The Society's Rules format has also changed to a loose-leaf, numerically indexed style.

It is the intent of this paper to provide surveyors with an up-to-date guide concerning the fire protection, detection and extinction aspects as set out in Chapter II-2 of the 1981 Amendments to SOLAS '74 and Part 6, Chapter 4 of the Society's Rules. Whilst some of the basic information contained in Mr Coggon's paper has not changed it is nevertheless reproduced here such that cross-reference by surveyors to other documents is kept to a minimum. Additionally, it is considered that whilst the regulation requirements in the International Maritime Organisation (IMO) document may have reduced its bulk by repetitive reference for each ship type to a basic set of regulations, the Society's surveyors may find the following presentation easier to follow.

It should be noted from the outset that the 1981 Amendments to SOLAS '74 only contain amendments to Chapters II-1, II-2, III, IV, V and VI and that the Articles of SOLAS '74 and Chapter I remain unaltered, that is, matters concerning the applicability of the regulations and the certificates to be issued.

Insofar as compliance with the International Convention is concerned, this paper addresses the fire safety requirements for ships the keels of which were laid, or were at a similar stage of construction, on or after the 1 September 1984. For ships constructed before that date the provisions of the convention in force at the date of build remain applicable except as provided otherwise for tankers in Chapter II-2 of the Annex to the Protocol of 1978 relating to SOLAS 1974 and also as provided otherwise for existing passenger ships in the successive conventions.

The effective date of the changes in the Society's Rules concerning, among other things, the 1981 Amendments is, however, the 26 January 1985, the date of approval of the original midship section or equivalent structural plans being the Society's equivalent to keel laying.

Thus great care will need to be exercised in the case of ships with midship section plans approved before the 26 January 1985 and keel laying on or after the 1 September 1984. The vessel's intended flag and whether the Society has been authorised to act on behalf of that administration will be determining factors in the Society's involvement in the requirements for that ship.

1. HISTORICAL NOTE

The history of international fire safety is interesting in its own right. Whilst a detailed knowledge of the history is not essential to enable application of such regulations it is a useful aid to understanding the reasons for them and, consequently, in interpreting them.

The regulations are contained successively in the 1929, 1948, 1960 and 1974 International Conventions for the Safety of Life at Sea (SOLAS), the Protocol of 1978 relating to SOLAS 1974 and the 1981 Amendments to SOLAS 1974.

All of this legislation, with the exception of the 1929 and 1948 conventions, was introduced by IMO after development by its Sub-Committee on Fire Protection. This Sub-Committee meets formally for only one week each year, therefore, the speed of development of new regulations is limited. Whilst over the years it has been obvious that new regulations were necessary in many specific respects, priority had to be given to the ship types and hazard risks where the greatest number of explosions and serious fires were occurring at the particular time. Fire casualties are emotive and receive widespread coverage in the news media. Thus pressure for changes in the regulations often comes from the public and parliament, or its equivalent in other countries. The number of lives lost and, latterly, the effect on the environment are factors which exacerbate such emotions.

The first convention in 1929 was the result of an international conference being called subsequent to the tragic loss of the British passenger ship "TITANIC". Since that disaster was the result of a collision with an iceberg which caused extensive flooding and many lives were lost due to an inadequate provision of lifeboat capacity, the 1929 convention is mainly concerned with sub-division and life-saving appliances. It contains little relating to fire safety and that only applicable to passenger ships.

It was the 1948 Convention which introduced the International Passenger Ship Safety Certificate and the Cargo Ship Safety Equipment and Safety Radio Certificates. This heralded the Society's involvement in the survey and certification of ships in those respects on behalf of several governments. The Passenger Ship Safety Certificate dealt with, among other things, requirements for structural fire protection, fire detection and fire extinction. The Cargo Ship Safety Equipment Certificate dealt with, among other things, fire extinguishing arrangements.

The 1960 Convention introduced the Cargo Ship Safety Construction Certificate which has, among other things, requirements for structural fire protection, although this amounts only to the provision of B-Class corridor bulkheads where they form escape routes to the lifeboat embarkation stations. The fire safety requirements for passenger ships were also slightly improved at this time.

The 1974 Convention is a repeat of SOLAS 1960, but incorporates the resolutions which were adopted by IMO in the intervening period. Perhaps more importantly, it also adopted a new procedure which requires that amendments to the convention automatically come into effect at the end of two years, or another period which is not less than one year at the discretion of the IMO Maritime Safety Committee (MSC), unless either more than one third of the Contracting Governments, or Contracting Governments whose combined fleets constitute not less than 50 per cent of the world merchant fleet, register an objection. This means that it will no longer be necessary to wait for years for a convention, or amendments to

a convention, to come into force. It may be remembered that the 1948 Convention took four years to enter into force, the 1960 Convention five years and the 1974 Convention six years.

Among the resolutions which were incorporated into the 1974 Convention were improvements in the fire safety requirements for passenger ships, including existing ships carrying more than 36 passengers and also the much improved safety measures for tankers which had been developed in 1975 following the explosions in the VLCC's "MACTRA", "MARPESSA" and "KONG HAAKON VII".

At this time the fire safety requirements of SOLAS had become so voluminous that they were given a chapter to themselves, viz Chapter II-2.

At the time of developing the new requirements for tankers the urgency had been so great as a result of the VLCC explosions referred to and others in a number of OBO ships, that the requirement for inerting the cargo spaces was only made applicable to new tankers of 100 000 tonnes deadweight and upwards and new combination carriers of 50 000 tonnes deadweight and upwards. These parameters were adopted as an interim measure for no other reason than to halt the explosions in the largest ships.

However, explosions continued to occur in tankers, particularly during the tank washing process, and a further conference was convened to address the matter. The outcome was the Protocol of 1978 Relating to the International Convention for the Safety of Life at Sea, 1974. This extended the requirement for inert gas systems down to 20 000 tonnes deadweight for all new tankers and also to some existing tankers on a time scale depending on the size of the ship, the type of the cargo, the capacity of the tank washing machines and whether the ship is operating with a cargo tank cleaning procedure using crude oil washing. The Protocol also introduced amendments to the regulations for the safety of navigation as a result of pressure from the USA Administration.

So great was the concern at IMO about the continuing tanker explosions and conviction that the answer lay in the provision and proper use of inert gas systems, that in 1979 they expanded and improved the requirements for inert gas systems as set out in Regulation 62 of Chapter II-2 of SOLAS 1974. Further, it was found that ships with inert gas systems were experiencing explosions either because of faults in the systems, in their operation, or indeed because although fitted the systems were not being used at all. Consequently in 1980 IMO published guidelines on the design, operation, maintenance and testing of such systems.

Under the amendment procedure, which was introduced in the 1974 Convention, the MSC of IMO in 1981 adopted amendments to Chapters II-1, II-2, III, IV, V and VI of SOLAS 1974. These include amendments to the fire safety requirements for tankers together with new and greatly expanded requirements for cargo ships generally. The more important of these changes relate to the adoption of improvements which were developed in 1975 concerning requirements for structural fire protection in all cargo ships, carriage of dangerous goods, and even more stringent requirements concerning cargo tank venting, purging, gas freeing and ventilation in tankers.

The introduction of these latest amendments so increased the volume of legislation that Chapter II-2 was rearranged at the same time with a view to reducing its size as much as possible, but it still remains a bulky document.

The 1981 Amendments to SOLAS 1974 came into force on the 1 September 1984 and already further amendments, namely those of 1983, are in print and intended to enter into force in 1986. The technical content of the 1983 Amendments to SOLAS 1974 is not discussed in this paper. Suffice to say that they have some relatively minor improvements in the fire safety regulations and introduce two new volumes setting out regulations for chemical tankers and liquefied gas carriers which of course include fire safety requirements for those ship types.

The Society's Rules are inevitably tied to a large extent to the Regulations of the International Conventions. This is a similar practice in all the classification societies although there are variations in the way in which this is done. Lloyd's Register of Shipping's Rules are so arranged that compliance will ensure that the corresponding requirements of SOLAS are also complied with, subject of course to variations of interpretation by the national administrations concerned. However, the Society does not slavishly copy the SOLAS regulations effective at any particular time and on several occasions has incorporated important changes in the Rules, such as the 1971 improvements in the fire safety requirements for tankers, well ahead of the national administrations. Further, as in other fields of its activity, the Society exercises an appreciable influence on the development of fire safety regulations at IMO. Along with the other members of the International Association of Classification Societies (IACS), the expertise of Lloyd's Register of Shipping in this field is both acknowledged and consulted.

The Assembly resolutions which are incorporated in the amendments to the International Convention for the Safety of Life at Sea 1974 are shown in Table 1.

Table 1 Assembly resolutions which are incorporated in the amendments to the International Convention for the Safety of Life at Sea, 1974

		incorporated in
A.210(VII)	Recommendation on Steering Gear for Large Ships	Ch.II-1, Reg.29
A.211(VII)	Recommendation on Safety Measures for Periodically Unattended Machinery Spaces of Cargo Ships Additional to those normally Considered Necessary for an Attended Machinery Space	Ch.II-1, Part E
A.323(IX)	Recommendation to Ensure Uniform Treatment of Ships Designed for the Carriage of Vehicles involved in the International Road Transport of Goods	Ch.II-1, Reg.16
A.324(IX)	Recommendation on Position of Collision Bulkheads in Cargo Ships	Ch.II-1, Reg.11
A.325(IX)	Recommendation Concerning Regulations for Machinery and Electrical Installations in Passenger and Cargo Ships	Ch.II-1, Reg.3, Parts C, D and E
A.326(IX)	Amendments to the Draft Regulations Concerning Fire Safety Measures for Tankers and Combination Carriers annexed to Resolution A.271(VIII)	Ch.II-2, Reg.61
A.327(IX)	Recommendation Concerning Fire Safety Requirements for Cargo Ships	Ch.II-2, Parts A and C
A.335(IX)	Recommendations Related to Chapter IV of the International Convention for the Safety of Life at Sea	Ch.IV, Parts A, B, C, Regs.7, 10 and 16
A.336(IX)	Recommendation on the Carriage of VHF Radiotelephone Stations	Ch.IV, Part C Reg.17
A.344(IX)	Recommendation on Search and Rescue Signals between Aircraft and Ships	Ch.V, Reg.16
A.345(IX)	Recommendation on Marking and Labelling of Dangerous Goods	Ch.VII, Reg.4
A.372(X)	Recommendation Concerning Fire Safety Requirements for Passenger Ships Carrying not more than 36 passengers	Ch.II-2, Parts A and B
A.418(XI)	Revised Regulation 62 of Chapter II-2 of the International Convention for the Safety of Life at Sea, 1974	Ch.II-2, Reg.62

2. UNDERSTANDING FIRE

2.1 The Nature of Fire

Fire is a chemical reaction in which elements, such as carbon and hydrogen, are combined with oxygen, resulting in a release of energy in the form of heat and light.

When some substances are heated they exude vapours and when these vapours are heated further, a temperature is reached at which vapour is evolved in sufficient quantity to be ignited if a source of ignition is present. This temperature is called the *flash point* or *ignition temperature*.

If the unignited vapours are heated still further, they reach a temperature at which they will ignite without the presence of a source of ignition. This temperature is called the *auto-ignition temperature*.

Fire requires the presence of three essential elements; fuel, heat and a supply of free oxygen, usually in air.

It follows that to prevent the occurrence of fire, it must be ensured that one or more of these essentials is excluded. Similarly, for the successful extinction of a fire, one or more of the elements must be removed.

There are exceptions to the general principle that a supply of air is necessary to form a flammable mixture. The quantity of oxygen contained in nitrates and chlorates may support combustion without the presence of air and these substances present serious explosion risks when carried in the holds of ships. Fires in nitrates and chlorates are extinguished by the copious application of water from hoses, led through open hatches.

In conditions where there are combustible materials, so situated in relation to a fire that they are capable of ignition, a fire will spread upwards and outwards from the original point of ignition by the convection, radiation and conduction of heat.

Between 75 and 85 per cent of the heat transferred away from a fire is accounted for by convection. Heat is released from a fire at temperatures in the region of 800 to 1200 deg.C. At these temperatures air is expanded to about a quarter of its density at normal atmospheric temperatures. It is also entrained by the hot gases produced by the fire to form a convection current, travelling upwards with a high velocity as a turbulent column, spreading heat above and around the area of combustion. This results in, among other things, an inflow of cooler, denser fresh air to the base of the fire, whereby the rate of combustion or intensity of the fire is increased and its rate of growth accelerated.

These convection currents can quickly raise the temperature of combustible materials in their path to the ignition point and, where unrestricted, can cause the fire to spread rapidly to areas remote from the original outbreak. This occurs either directly, or through secondary outbreaks caused by the ignition of combustible vapours contained in the gases from the fire which have not been consumed because of oxygen starvation within the fire, but on reaching supplies of fresh air some distance from the fire, burst into flame. This latter phenomenon can be seen when areas of flame appear in the smoke at considerable distances from the seat of a large fire.

When a fire occurs in an enclosed compartment the hot gases rise to the ceiling, where they spread out to form a hot layer. As the fire proceeds, this layer increases in temperature and depth and when all the oxygen has been used up, the fire dies down to a smouldering mass with an atmosphere above consisting of combustion gases and unburned combustible vapours at or above their ignition temperature. If a door or window is opened fresh air will be drawn into the compartment and the unburned combustible vapours will burst into flame with almost explosive force. This phenomenon is referred to as *flash-over* and often constitutes the division between a controllable minor outbreak and a major outbreak which could result in abandonment of the ship.

Radiation is responsible for the spread of fire to a lesser but significant degree. Combustible materials laterally adjacent to a fire may be unaffected by convection currents, but heat radiated from the flames may cause the evolution of vapours which are drawn toward the fire and ignited.

Fire may also be spread by the conduction of heat by materials with suitable characteristics. Ships are largely constructed of steel, which is a good conductor of heat, and special precautions must be taken to restrict the spread of fire from one compartment to another by the conduction of heat through the structure.

It is a fundamental fact that fire creates the conditions for its own growth and, with growth, its potential for growth increases. It is essential to safety that fire should be controlled and, if possible, extinguished without delay, otherwise it may develop to proportions at which it will be beyond the capacity of the available extinguishing equipment. This is even more important on board ship than on land, since the equipment available is very limited and help from outside sources will probably be unavailable.

In addition to heat and flames, most fires produce smoke and an assortment of gases, some of which are toxic or asphyxiating. Smoke obscures the location of a fire so that one of the major problems of fire fighting is that of locating the seat of the fire. It also obscures escape routes, thus creating difficulties for personnel who are trying to escape from their cabins, perhaps on the lower decks, to the lifeboat embarkation deck, or assembly positions.

The principal gases present in a fire are carbon monoxide and carbon dioxide, although significant quantities of other gases may also be present, depending on the materials involved.

Carbon monoxide is preferentially absorbed by the haemoglobin of the blood and deprives the body of oxygen; two to three breaths of this gas at low concentrations in air can produce unconsciousness and death within two to three minutes.

Carbon dioxide is not so toxic; unconsciousness occurs at a concentration of about 9 per cent. However, the increased breathing rate, stimulated by the inhalation of small quantities, increases the intake of other combustion products which may also be toxic or asphyxiating.

The physiological effects of this combination of combustion products, are to incapacitate a person through its powerful irritant action on the eyes, nose, throat and lungs, and to partially or totally reduce vision.

Psychologically, the sight or smell of smoke may induce panic, even when it appears in an area as yet unaffected by heat or flames.

Of the deaths which are attributed to fire, the vast majority are caused by the asphyxiating and toxic effects of smoke and the accompanying combustion gases.

2.2 General Principles of Fire Protection

The ultimate aim of any fire protection system is to prevent the outbreak of fire, however it should be recognised that this is a perfect ideal that is unlikely to be achieved due to either engineering compromise or human error. For example electrical faults which could give rise to the risk of fire cannot be totally eliminated but can be minimised by good design, construction and installation. Also the location of an oil fuel unit such that a leak could come in direct contact with a hot surface could lead to the outbreak of fire.

Thus the good engineering practices of surveyors dealing with aspects other than those discussed in this paper have a large part to play in approaching the ultimate aim. The fire protective measures addressed by the Convention and the Society's Rules concern reducing, as far as practicable, the amount of combustible material used in the construction and to some degree the outfit, the division of the ship by structural and thermal boundaries into areas such that containment of any fire will be within the fire fighting capability of the ship's crew and equipment and finally the segregation from each other of high fire risk areas such as cargo spaces, machinery spaces and

accommodation areas. Having thus made provision to contain the fire it is important that early detection is achieved in order that the crew should have a reasonable chance of extinguishing it. Detection can be achieved by a combination of automatic fire detectors and manually activated fire alarm systems. A variety of hand portable appliances and fixed equipment suitable for fighting fires of all anticipated types and magnitudes must be provided to extinguish any fire as quickly as possible.

It should be noted, however, that regardless of the obligations imposed by statutory regulations and the Society's Rules to provide the foregoing, this will have been to no avail if the ship's crew have not been trained to use the fire fighting equipment efficiently or to react in a responsible manner on discovering a fire. This is especially important on passenger ships and floating hotels where two types of crew will be on board, marine and non-marine (stewards, dining room staff etc) where the potential for disaster involving large numbers of people is increased.

When fighting a fire, should a point be reached where the magnitude is beyond the capability of the extinction equipment available the only recourse for the personnel involved is to make an orderly escape and abandonment. Thus care must be taken concerning the disposition and protection of escape routes and stairways leading to the lifeboat embarkation areas and the proper siting of the life saving appliances.

It will, therefore, be seen that marine fire protection is a combination of passive and active defence which together form an integrated system. Most fires start in a small way and can readily be extinguished by using the proper hand-portable equipment. Failure at this early stage to extinguish a fire could have disastrous consequences.

The SOLAS Regulations also address fire safety in two separate parts; passive (structural fire protection, escape routes, etc.) and active (detection and extinction systems). The ship types to which the Regulations apply are:

(i) Passenger ships (of any size)
(a) carrying more than 36 passengers.
(b) carrying up to 36 passengers.

(ii) Cargo ships. (500 gross tons and above).

(iii) Tankers and Combination carriers. (500 gross tons and above).

Flow diagrams of all the Regulations applicable to each ship type are given in Figures 1, 2 and 3*. These are arranged to show the requirements for the passive and active systems divided into areas concerning machinery spaces, accommodation spaces, cargo spaces and general requirements for the vessel.

Gross tonnage or deadweight is an important factor in the applicability of many of the Regulations and Table 2 highlights these.

The sections following describe in detail all of the individual requirements shown in the flow diagrams and are arranged in a similar sequence to that appearing in the Convention, beginning with the active systems.

3. FIRE DETECTION AND EXTINCTION

3.1 Definitions and Designations of Classes of Fires

The British Standards Institution gives the following designations for the purpose of classifying fires of different natures in order to simplify spoken and written reference to them:

Class A — These are fires involving solid materials, usually of an organic nature in which combustion normally takes place with the formation of glowing embers (usually carbonaceous fires).

Class B — These are fires involving liquids or liquefiable solids.

Class C — These are fires involving gases.

Class D — These are fires involving metals.

3.2 Fire Extinguishing Agents

The substances which may be used for extinguishing fires on board ships are (1) water (2) halogenated hydrocarbon (3) foam (4) carbon dioxide (5) inert gas (6) nitrogen.

Due to the very wide range and types of cargo being transported by sea in increasingly sophisticated vessels the choice of fire extinguishing agent for a particular hazard should be carefully considered. Some agents are more efficient than others, some conduct electricity, some are toxic and others may do more damage than the fire itself. Some would not extinguish the fire whilst others would exacerbate the incident, for example, when a jet of water is applied to the surface of an oil fire the burning oil would be splashed about spreading the fire.

The fire fighting equipment should be simple to operate and of a robust construction not subject to deterioration in the marine environment. Where appropriate clear and concise operating, maintenance and testing instructions should be prominently displayed for each item of equipment.

3.2.1 Water

Water is a coolant having a capacity for absorbing heat far in excess of any other commonly used medium. As it extracts heat from the fire it turns into steam which has a smothering effect. It may be applied in a solid jet to Class A fires involving solid materials such as wood, paper and fabrics achieving deep penetration to the seat of the fire. A fine spray of water is effective in extracting heat from the flames from burning liquids without seriously disturbing the surface of the liquid. Water spray curtains are used to protect the front of superstructures facing the cargo tank deck and deck mounted cargo tanks from deck spillage fires. Water spray curtains generated at the nozzle of hand held hoses are also effective for the protection of the fire-fighter.

The disadvantages with the use of water are:

(a) It conducts electricity.

(b) It can cause considerable damage to cargo and machinery.

(c) It can cause considerable loss of stability when used in large quantities.

3.2.2 Halogenated Hydrocarbon Gas (Halon)

Halons are extremely effective extinguishing agents which have been used for some time in land based installations and in the field of aviation but due to their toxic properties had, until about ten years ago, not been accepted for use in the marine environment.

Extensive research has shown that some halons when released rapidly into the protected space achieve a rapid extinction of a fire and consequently, a small volume of toxic break down products.

Two halons, bromotrifluromethane (BTM or Halon 1301) and bromochlorodifluromethane (BCF or Halon 1211) are acceptable for use in ships classed by the Society although the use of the latter is limited. These liquids extinguish fires by interrupting the normal chemistry of combustion and are particularly effective in extinguishing fires where the energy of combustion is mainly concentrated in the flame. Unlike carbon dioxide they do not extinguish by smothering.

The advantages of halon are:

(a) It achieves incredibly rapid extinguishment of fires.

(b) It leaves no agent residue.

These figures are attached to inside back cover.

Table 2 Regulations governed by gross tonnage or deadweight (other than those for passenger ships of any size and cargo ships and oil tankers and combination carriers of 500 gt and above)

Solas Reg.	LR Rules Pt 6 Ch 4	Requirements	Passenger Ships	Cargo Ships	Oil Tankers
4.3.1.1	3.3.1	3 independently driven fire pumps	⩾4000 gt	—	—
4.3.1.2	3.3.1, 3.3.2	2 independently driven fire pumps	<4000 gt	⩾1000 gt	⩾1000 gt
4.3.1.3	3.3.3, 3.3.4	Power pumps	—	<1000 gt	<1000 gt
4.3.3.1	3.3.7(a)	All fire pumps not to be located in one compartment	⩾1000 gt	—	—
4.3.3.2	3.3.7(b)	Emergency fire pump	—	⩾2000 gt*	⩾2000 gt*
4.3.3.3	3.3.8	Alternative means of providing water	<1000 gt	<2000 gt**	<2000 gt**
4.3.4	3.3.10	Ready availability of water:	—	—	—
4.3.4.1	3.3.10(a)	In any interior location from any hydrant	⩾1000 gt	—	—
4.3.4.2	***	To the satisfaction of the administration	<1000 gt	All	All
4.3.4.3	3.3.10(b)	Remote starting of the main fire pumps	—	<1600 gt	<1600 gt
4.4.2	3.6	Minimum pressure in the fire main:			
		0.31 N/mm²	⩾4000 gt	—	—
		0.27 N/mm²	⩾1000 gt but <4000 gt	⩾6000 gt	⩾6000 gt
		0.25 N/mm²	—	⩾1000 gt but <6000 gt	⩾1000 gt but <6000 gt
		Sufficient pressure to produce a satisfactory jet throw	<1000 gt	<1000 gt	<1000 gt
4.7.4.1	3.9.4	Number of fire hoses	—	⩾1000 gt	⩾1000 gt
4.7.4.2	3.9.4	Number of fire hoses	—	<1000 gt	<1000 gt
5.2.2	4.2.2(b)	Reduction of CO_2 concentration in machinery spaces	—	<2000 gt	<2000 gt
6.7	5.6.1	Number of portable fire extinguishers	⩾1000 gt	⩾1000 gt	⩾1000 gt
—	5.6.1	Number of portable fire extinguishers	<1000 gt	<1000 gt	<1000 gt
7.2.3	6.2.1(d)	Non-portable fire extinguisher may be waived	<150 gt	<150 gt	<150 gt
19	3.11.1	International shore connection	⩾500 gt	⩾500 gt	⩾500 gt
28.3.2	17.6.5	Means of escape	⩾1000 gt	—	—
			<1000 gt	—	—
39.1	17.17.1	Protection of cargo spaces	⩾1000 gt	—	—
45.4	18.4.4	Means of escape	—	<1000 gt	<1000 gt
53.1.1	18.12.1	Protection of cargo spaces	⩾2000 gt	⩾2000 gt	—
56.1	19.3.1	Location of pump room	—	—	<25000 dwt
60.1	19.9.2	Fixed deck foam and inert gas systems to protect cargo tanks deck area	—	—	⩾20 000 dwt
60.8	19.9.1	Deck foam system	—	—	<20 000 dwt
61.5	19.10.5	Foam applicators in lieu of monitors	—	—	<4000 dwt
61.7	19.10.8	Hose connection only (P and S) on front of poop	—	—	<4000 dwt

NOTES
* ⩾1000 gt. *See* LR Rules Pt 6, Ch 4, 3.3.7(b).
** <1000 gt. *See* LR Rules Pt 5, Ch 4, 3.3.8.
*** Deleted from LR Rules.

(c) Halon 1301 containers can be located inside or outside some protected spaces.

(d) At the extinguishing concentrations required by the Society, Halon 1301 and 1211 are slightly toxic but have no after effects for exposures of a few minutes.

The disadvantages are:

(a) It is not so effective against solid materials in which fires quickly become deep seated.

(b) It has little cooling effect.

(c) It is unsuitable for use against combustible chemicals that contain oxygen, reactive metals and metal hydrides.

(d) The liquid is very expensive in comparison with CO_2.

The Convention also permits the use of Halon 2402 (Dibromotetra fluoroethane) but because of its relatively higher toxicity its use is not encouraged by the Society.

3.2.3 Foam

Foam is the most suitable medium for extinguishing fires involving flammable liquids. Extinguishing is achieved by forming a layer of small bubbles on the surface of the liquid preventing fuel vaporising. After extinguishing the flames by fuel starvation the foam blanket should be maintained to allow the surrounding structure to cool below the ignition temperature of the liquid.

The early type of foams were produced by a chemical reaction but have largely been replaced by mechanical foams of which there are two specific types; protein and synthetic detergent based. Whichever foam concentrate is used it requires to be mixed in some proportion with water, usually 3% or 6% concentration. Furthermore, the resulting solution must be forced through an inductor with a branch pipe, special nozzle or applicator in which a turbulence is set up and air induced into the mixture so that a fluid aggregation of air-filled bubbles is formed. All foam concentrates intended for marine fire fighting should be suitable for use with sea water.

3.2.3.1 PROTEIN FOAM is manufactured from animal waste products such as blood or hoof and horn meal, with a stabiliser added. It is cream in colour with an unpleasant smell. The foam solution is usually a mixture of 3% foam concentrate to 97% water. Protein foams are relatively stiff and slow draining; they do not tolerate fuel mixing and are heat resistant.

3.2.3.2 FLUOROPROTEIN FOAM (FP) is a protein foam to which a synthetic fluorocarbon surfactant has been added. This additive prevents fuel adhering to the foam bubbles when submerged in a flammable liquid and reduces fuel transfer through the air-excluding foam blanket. Fluoroproteins are more fluid than proteins; they will tolerate fuel mixing and have a good resistance to heat.

3.2.3.3 FILM FORMING FLUOROPROTEIN FOAM (FFFP) is a recent development which is a film forming foam with protein as its foaming agent. Because FFFP contains protein rather than synthetic detergents it has a higher degree of fuel tolerance and security than synthetic based products. In other respects it is akin to fluoroproteins whilst being fluid, film forming and acting as quickly as other film forming products.

3.2.3.4 SYNTHETIC DETERGENT FOAM is produced from a foaming agent similar to that from which hair shampoo and washing up liquids are manufactured. The foam solution consists of a 5% concentrate added to 95% water. This foam is more fluid and faster draining than protein foam but does not tolerate mixing with fuel.

Unlike other foam types which are only suitable for low expansion application, synthetic foams are very flexible and can be produced as low expansion foam at expansion ratios up to 12 to 1, medium expansion foam at ratios up to 150 to 1 and high expansion foam at ratios up to 1000 to 1.

Low expansion foam should be applied by monitors and hand held hoses and applicators. It can be projected through monitors up to about 100 metres but the greater the distance the greater will be the area over which foam is scattered.

High expansion foam is very light and will blow away and should only be used in enclosed compartments. It cannot be projected and is ducted or poured directly into the protected space. It should be used to entirely fill the protected space. When applied to a fire part of the foam is flashed to steam producing a mixture of steam and air, the oxygen content of the mixture being too low to support combustion. High expansion foam has considerable cooling properties and is an excellent shield against radiant heat, thus preventing the spread of fire. It is effective against fires involving low flashpoint liquids which do not readily dissolve in water. High expansion foam is produced by spraying an aqueous foam solution uniformly onto a fine nylon mesh, or stainless steel screen through which air is driven by a large capacity fan to form huge masses of bubbles at rates from 300 m^3 to 15 000 m^3 of foam per minute depending on the size of the unit.

3.2.3.5 ALCOHOL RESISTANT FOAM. The foam compounds previously mentioned are all suitable for use on hydrocarbon fires but are unsuitable for fires involving water-miscible liquids such as some alcohols (e.g. methyl, ethyl, isopropyl), esters (e.g. ethyl acetate), ketones (e.g. isopropyl ether, diethyl ether) which absorb water from the foam and thus break down the bubble walls. For this purpose alcohol resistant foams have been developed. These are also referred to as *All Purpose Foams* because they can also be used on ordinary hydrocarbon liquid fires, although it should be noted that they are not as suitable for that purpose as the other previously mentioned foams and may require an increased application rate to achieve extinction.

3.2.3.6 AQUEOUS FILM FORMING FOAM (AFFF) is a synthetic detergent foam to which a synthetic flurocarbon surfactant has been added. The foam usually consists of a 3% to 5% concentrate added to 97% to 95% water. The foam is very fluid, provides a vapour securing film, will tolerate some fuel mixing and is faster draining than fluoroprotein foam. In use, solution draining from the foam produces an aqueous film on the surface of hydrocarbon fires contributing to rapid vapour suppression, fire extinction and prevention of flash-back.

A new development is a 1% concentrate with lower burnback characteristics and suitable for use at lower ambient temperatures.

In order to decide which foam concentrate is most suitable for the purpose intended the following should be considered:

(a) Speed of extinction.

(b) Burnback and reignition resistance.

(c) Fuel tolerance.

Table 3 gives a summary of the major foam types and their attributes.

Table 3 Summary of major foam types

	Protein	Synthetic Detergent	Fluoro-protein	AFFF	FFFP
Speed of Extinction	P	G	G	E	E
Burnback and Reignition Resistance	G	P	G	F	G
Fuel Tolerance	P	P	G	F	E

(P = Poor, F = Fair, G = Good, E = Excellent)

3.2.4 Carbon Dioxide Gas

For many years carbon dioxide has been successfully applied to machinery spaces and almost every kind of risk material in ships holds. Fire smothering is achieved by diluting the oxygen content of the atmosphere in the compartment from the normal 21 per cent to a level which is insufficient to support combustion. For most substances this is in the range of 12 to 16 per cent, but for smouldering solid combustible materials a reduction to 5 per cent may be necessary to achieve complete extinction.

The advantages of carbon dioxide are:

(a) It is non-corrosive.

(b) It does not conduct electricity.

(c) It leaves no residue.

(d) It is not subject to deterioration in quality with age.

(e) It is always immediately available.

Its disadvantages are:

(a) It is highly asphyxiating and slightly toxic, a concentration of about 9 per cent would produce unconsciousness within a few minutes.

(b) It has little cooling effect and there is consequently a danger of re-ignition if air is re-admitted to the compartment too soon after the fire.

(c) When discharged, particles of solid carbon dioxide are normally present and can generate sufficient static electricity to produce an incendive spark which could ignite flammable atmospheres such as may be found in ships. For this reason carbon dioxide is unsuitable as an inerting medium in cargo oil tanks and pump rooms.

3.2.5 Inert Gas

Inert gas, when considered by the marine industry for fire protection purposes, usually refers to boiler flue gas or gas produced by burning diesel fuel. Both these systems are used in oil tankers for inerting the atmosphere of the cargo tanks in order to prevent explosions. The gas produced consists of about 14 per cent carbon dioxide, about 1 per cent oxygen and about 85 per cent nitrogen, although there are other trace elements present.

Inert gas is a mixture of gases some of which are asphyxiating or toxic and before a tank is entered great care must be taken to ensure it has been effectively ventilated and all toxic trace elements removed.

3.2.6 Nitrogen

Nitrogen may be used as a fire smothering agent or as an inert gas where other types of inert gas are unacceptable to the shipper because they would contaminate the cargo. It is a gas with a density slightly less than that of air. The concentration required to extinguish a fire is higher than that required for CO_2.

The general use of nitrogen as an extinguishing agent has been limited by its low critical temperature, minus 147°C.

3.3 Fire Main System

Water is readily available in unlimited quantities and thus the fire water main should form the backbone of the fire fighting systems in the ship. The water system should be capable of efficient operation and arranged to deliver water through hydrants located so that a minimum of two powerful jets of water from hoses and nozzles can reach all parts of the ship normally accessible to the passengers and crew and any part of any cargo space when empty. One of the jets of water must be available from a single length of hose.

3.3.1 Fire Pumps

Water is to be supplied by at least three independently driven fire pumps in passenger ships and two in cargo ships, although this requirement may be reduced in smaller vessels of both types. In cargo ships not less than two designated fire pumps are to be located in the main machinery space. In addition in cargo ships one of the general pump, bilge and ballast pump or other similar pump is to be connected to the fire main. However, this connection is required only if one of these pumps already has the required capacity and discharge pressure. The total capacity of fire pumps in passenger and cargo ships should be two thirds of the quantity required for bilge pumping but in cargo ships the total capacity need not exceed 180 m^3/hour. Sanitary, bilge, ballast and general service pumps can be used for fire fighting purpose, providing they are not normally used for pumping oil. Occasional duty for pumping or transfer of oil with suitable changeover arrangements is permissible.

The fire pumps should be arranged so that a fire in any one compartment will not put all the required pumps out of action. In passenger ships this is achieved by locating at least one pump in a separate compartment but in cargo ships, which normally have only one engine room, a fixed independently driven emergency fire pump located outside the engine room should also be provided.

The emergency fire pump is to be capable of supplying two satisfactory jets of water through the available hoses and nozzles and have a capacity not less than 40 per cent of the total required capacity of the fire pumps and in any case not less than 25 m^3/hour.

Whether electrically or diesel powered, the emergency fire pump should be situated so that it will not be readily affected by smoke or fire from the space containing the main fire pumps. If diesel driven, the power sources should be capable of being readily started by hand down to an ambient temperature of 0°C. If necessary, heating arrangements should be installed. Where batteries are the sole means of starting, two sets should be provided each set being capable of six starts within 30 minutes and at least twice within the first 10 minutes. One of the sets of batteries should be on constant trickle charge and a hand started battery charger is to be provided. The service fuel tank for diesel drivers would normally be in the same compartment and must contain sufficient diesel to run the pump for three hours on full load. A reserve tank holding sufficient diesel for a further 15 hours at full load is also to be provided. Air inlets to the space containing the pump should be arranged to minimise the possibility of engine failure due to ingress of smoke or water. If electrically driven the source of power should be the emergency generator. Electric cables from the generator to the emergency fire pump should not pass through the space containing the main fire pumps. The emergency fire pump should preferably have an independent sea suction located outside the space containing the main fire pumps. Where the pump is located in a space, such as above the after peak, and the sea suction requires

to be fitted inside the engine room then the sea inlet valve should be controlled from a position adjacent to the emergency fire pump. The valve should remain in the open position at all times and be controlled by an extended spindle or hydraulic operation such that in the event of power failure the valve stays open. Any suction pipe located inside the engine room is to be encased in a substantial steel trunk or alternatively be heavy gauge pipe. The sea suction should be located such that efficient operation will be maintained in all conditions of list and trim likely to be encountered.

The space containing the fire pump is considered a "control station" for the purpose of determining the fire insulation from Table 8b.

Direct access between the machinery space and emergency fire pump compartment should not generally be permitted but, where necessary, may be by means of an air lock with two self closing doors, or through an approved type of watertight door capable of remote operation from a space not likely to be cut off in the event of fire in the engine room or emergency fire pump space. In the latter case a second means of access to the space containing the emergency pump must be provided.

In tankers, fire pumps are not to be situated in pump rooms, cofferdams and other spaces liable to contain explosive vapours or in spaces immediately adjacent to cargo oil or slop tanks. It should be ensured that door and ventilator openings to the compartment and any air inlets for the pump are situated, in relation to cargo tank openings such as vent pipes and P.V. valves, to preclude the possibility of drawing dangerous vapours into the compartment.

When the emergency fire pump is situated in a compartment forward of the cargo tanks of an oil tanker and below the level of the cargo tank deck and having access onto that deck, it should be ensured that flammable vapours cannot be drawn into the space. In such cases the opening onto the cargo tank deck is to be fitted with an air lock with two self closing doors and the compartment mechanically ventilated with the air inlet situated remote from any hazardous area.

In deep draught ships, to overcome the difficulty in achieving an adequate delivery from the emergency fire pump into the fire main, a hydraulic pump driven by a diesel pump situated at deck level is fitted at a low level in the ship. The hydraulic pump will raise the water to the diesel pump which then delivers it into the fire main at the required rate.

The water supply on passenger ships of 1000 tons gross and over is to be such that one effective jet of water from any interior hydrant is readily available, the continuation of the output of water being ensured by automatic starting of a fire pump. In cargo ships with an unmanned machinery space or when only one person is on watch, immediate water delivery from the fire main system at a suitable pressure is required either by remote starting of one of the main fire pumps from the navigating bridge or fire control station, if any, or permanent pressurisation of the fire main system by one of the main fire pumps.

3.3.2 Piping

Materials readily rendered ineffective by heat should not be used for mains and hydrants. Steel pipes are to be galvanised both internally and externally. Cast iron pipes are not acceptable. Butterfly and diaphragm valves with soft seatings are not accepted for isolating purposes unless certified as having passed a fire test as described in Appendix A or equivalent. The pipes and hydrants should be located so that the fire hoses may be easily coupled to them. Where deck cargo is carried care should be taken to guard against damage to the fire main. Relief valves must be placed in the fire main if the fire pumps could develop a pressure in excess of the design pressure of the main. Unless one hose and nozzle is provided for each hydrant in the ship there should be complete interchangeability of hoses and nozzles.

Isolating valves are to be fitted to segregate the rising main within the machinery space containing the main fire pump or pumps from the rest of the fire main. These valves must be fitted outside the machinery space in an easily accessible and tenable position. The fire main should be arranged so that when the machinery space isolating valves are shut all hydrants in the ship can be supplied with water from pipes which do not re-enter the machinery space.

The fire main should be available for fire fighting purposes at all times and permanent connections to other services are not generally permitted. It is, however, permissible to fit branches for such low demand services as hawsepipe cleaning, and forepeak and chain locker bilge eductors. The topside water ballast tanks in vessels carrying low fire risk cargoes may be filled through a flexible hose connected to the fire main. This hose should be immediately removed after use and a notice to this effect prominently displayed at each connection point.

3.3.3 Hoses and Nozzles

Fire hoses are to be of an approved material, of which there are several, the most common being constructed from synthetic woven textiles, lined with rubber and coated with P.V.C. These hoses are very strong; not affected by oils, most chemicals, mildew and extremes of climate. This type has largely replaced the earlier canvas hose which was very susceptible to mildew, especially if not properly dried after use.

Hoses should have a length not exceeding 18 metres, although for ease of use 12 metres in machinery spaces is often preferred. Lined hoses today generally are $1\frac{1}{2}''$ and $1\frac{3}{4}''$ diameter which gives a much more manoeuvreable piece of equipment than the earlier commonly used $2\frac{1}{2}''$ diameter hose and both produce an identical jet through the same nozzle as the $2\frac{1}{2}''$ diameter hose.

In a passenger ship there is to be at least one fire hose for each required hydrant. In cargo ships over 1000 tons gross there is to be one for each 30 metres length of the ship plus one spare, but in no case less than five in all. That number does not include hoses required in engine or boiler rooms. In cargo ships less than 1000 tons gross not less than three hoses are required.

Nozzles should be 12 mm, 16 mm and need not exceed 19 mm and be dual purpose type incorporating a shut off. Nozzles may be manufactured from brass, aluminium and copper alloy, or suitable plastic.

An international shore connection should be provided with facilities for use on either side of the ship to enable the deck main to be supplied by water from ashore.

3.4 Water Spray Systems

Water spray systems may be used in machinery spaces, cargo pump rooms and spaces where vehicles are carried. There are many factors which affect the fire extinguishing efficiency of a water spray system and include, *inter alia,* the diameter of the pipelines, the position of orifice plates to balance the system, the discharge pressure and droplet size, the spray head orifices, their impingement angle and cone angle and the velocity of the spray at the nozzle head. It is essential that the impingement angle and cone angle are correct for the hazard to be protected to ensure that total coverage of any flammable surface is achieved.

One method which could be used to test that satisfactory coverage is being achieved is to collect the water being discharged in trays and measure the quantity in a specific time.

(a) Machinery Spaces and Cargo Pump Rooms

A fixed water spraying system fitted in machinery spaces and cargo pump rooms should consist of a water main and branch pipes fitted with nozzles. The nozzles are to be of a type suitable for extinguishing burning oils and located to ensure reasonably uniform distribution of water. Particular attention should be paid to the location of nozzles in way of bilge and tank top areas, boiler fronts, oil fuel burning units, separators and purifiers.

The system may be divided into sections and the distribution valves operated from a readily accessible position outside the protected space which will not be readily cut off by fire. Water is to be delivered by a pump capable of supplying at the required pressure the necessary demand for the protected space. The system should be permanently pressurised and the pump is to start automatically by a pressure drop in the system. The pump, its controls and sea inlet should be located outside all spaces being protected. The pump may be diesel driven but if powered from the emergency generator it is to be arranged to start automatically in case of main power failure. The system should be capable of providing a uniform distribution of water throughout the protected space at a minimum rate of 5 litres/m^2 per minute.

(b) Special Category and Ro/Ro Cargo Spaces (*See* Figure 4)

These spaces permit the unrestricted movement of vehicles throughout their length and breadth and consequently special problems are present when attempting to fight and restrict the spread of fire. Fixed gas systems because of their asphyxiating or toxic properties are not permitted where access is allowed to personnel at any time, low expansion foam is unsuitable, and high expansion foam would be required in such quantities as to make it impractical. Therefore, the most suitable alternative to deal with flowing petrol fires is a fixed water spraying or drencher system capable of delivering large quantities of water quickly over a wide area. However, the possible accumulation of large quantities of water on the vehicle deck can lead to serious stability problems and great care should be exercised in the design and positioning of deck scuppers.

The pipes and nozzles of a water spray system are to be evenly distributed on the underside of the deckhead and any hoistable car decks to ensure that all horizontal and vertical surfaces are effectively covered. The nozzles should be of full bore type to give an application rate of 3.5 litres per minute of deck area for spaces not exceeding 2.5 metres in height and 5 litres per minute of deck area above 2.5 metres. The system should normally cover the full breadth of the vehicle deck and may be divided into sections provided that they are at least 20 metres in length. In ships where the vehicle deck space is subdivided with continuous longitudinal "A" class divisions the space may be considered as forming two longitudinal sections.

The distribution valves for the system are to be situated in a readily accessible position adjacent to but outside the protected space which should not be readily cut off by a fire within the space. The space containing the distribution valves is to be adequately ventilated and have direct access provided from the vehicle deck space and from outside that space.

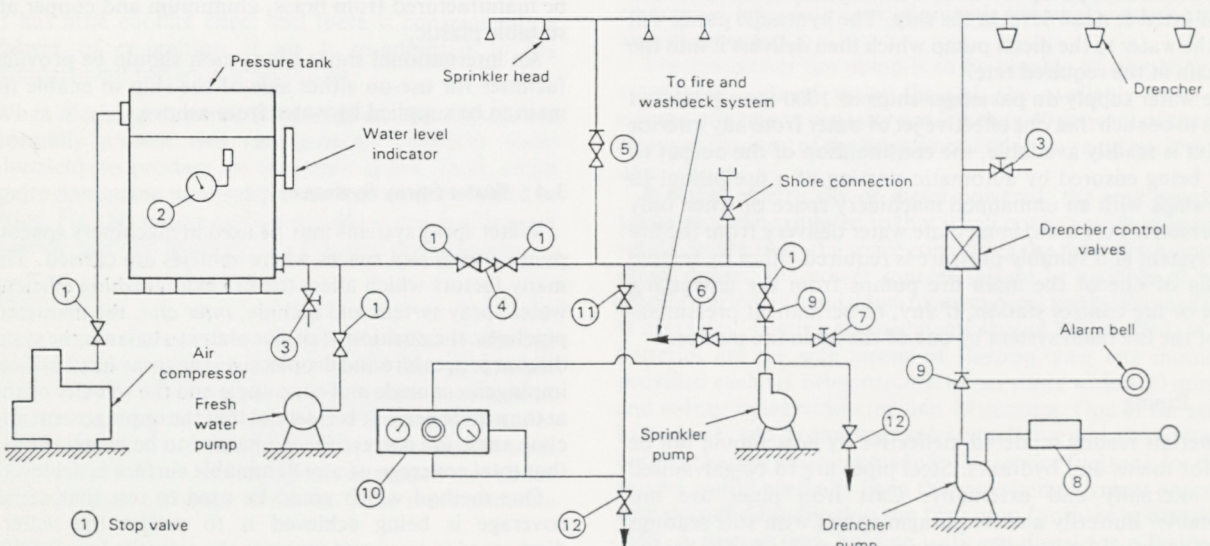
The supply to the system is to be from a water main connected to a sea-water pump where the pump or pumps should be:

(i) Additional to the pumps provided for normal fire fighting purposes. The pumps should be connected to the fire main by a lockable non-return valve to prevent back flow to the fire main.

(ii) Capable of providing simultaneously and at all times a sufficient supply of water at the required pressure to all nozzles in the vehicle deck, or in at least two adjacent sections having the greatest aggregate application rate.

(iii) Capable of being brought into operation by remote control (which may be manually actuated) from the position at which the distribution valves are situated.

(iv) Situated in a position reasonably remote from the protected space.



(1) Stop valve
(2) Pressure gauge with safety valve
(3) Drain valve
(4) Back pressure alarm valve with fire alarm switch
(5) Sprinkler control valves
(6) Screw down non-return valve capable of being locked shut
(7) Screw down non-return valve locked shut
(8) Automatic pump starting with remote start button
(9) Pump delivery check valve
(10) Sprinkler pump automatic start pressure switch
(11) Stop valve
(12) Drain valve

Fig. 4 Automatic sprinkler, fire detection, fire alarm and water spray system

3.5 Automatic Sprinkler, Fire Detection and Fire Alarm System (*See* Figure 4)

An automatic sprinkler, fire detection and fire alarm system may be fitted in passenger ships as an alternative to a fixed fire detection and fire alarm system in all accommodation spaces, service spaces and control stations and in cargo ships in all accommodation spaces, galleys and other service spaces in which Method IIC is adopted.

This system has the distinct advantage that in addition to identifying the location of a fire and giving warning of its presence, it automatically initiates a fire fighting operation and thus satisfies one of the first fire fighting rules—to attack a fire at its earliest stage before it can develop into a major outbreak. On passenger ships with large areas of accommodation which may be unattended for long periods and in cargo ships which have greatly reduced crew numbers this system is highly desirable.

The system is to be capable of immediate and automatic operation at all times and, except for short sections of pipes, should be of a wet pipe type continuously charged with fresh water at the necessary pressure. Means for giving visual and audible alarms at indicating units should be provided for all sections of sprinklers. Each unit should indicate the location of a fire in a particular section at the navigating bridge, or alternatively, at the main fire control station on passenger ships.

Sprinkler heads should normally be the frangible bulb type. Sprinkler heads operated by other means may be accepted where it can be demonstrated that they are no less efficient. They should be grouped into separate sections each containing not more than 200 sprinklers. Generally in passenger ships any section of sprinklers should not serve more than two decks nor more than one vertical zone. Each section is to be capable of being isolated by one stop valve located in a readily accessible and clearly indicated position. A pressure gauge is to be provided at each section stop valve and at a control station. The sprinklers should be resistant to corrosion. Operation is required within the temperature range 68 to 79 deg.C except where high ambient temperatures might be expected when the operating temperature could then be increased by 30 deg.C above the maximum deckhead temperature.

Sprinklers are to be placed in an overhead position and spaced so as to maintain an average application rate of not less than 5 litres/m^2 per minute of deck area.

A pressure water tank with a minimum capacity for 2800 litres of fresh water is to be provided in a position reasonably remote from category A machinery spaces and not situated in any sprinkler protected space. The arrangement should provide for maintaining an air pressure in the tank such as to ensure that, when the standing charge of fresh water in the tank has been used the pressure will not be more than the working pressure of the sprinkler plus the pressure exerted by a head of water measured from the bottom of the tank to the highest sprinkler in the system. Means to replenish the air and water, indicate the water level in the tank and prevent the passage of sea-water into the tank are to be provided.

The sprinklers are to be fed from a main connected to a sea-water pump where the pump is:

(i) An independent power pump capable of continuously supplying water to the sprinklers and starting automatically by a pressure drop in the system before the tank of fresh water is exhausted.

(ii) Situated in a position reasonably remote from category A machinery spaces and not situated in any sprinkler protected space.

(iii) Capable of monitoring the necessary pressure at the level of the highest sprinkler to ensure a continuous output of water with a minimum coverage of 280 m^2 at an application rate of 5 litres/m^2 per minute of deck area.

(iv) Fitted with a test valve with a short open-ended discharge pipe on the delivery side.

Not less than two sources of power supply for the sea-water pump and automatic alarm and detection system are required. Where the sources of power for the pump are electrical they should:

(i) In passenger ships be a main generator and an emergency source of power. One supply is to be from the main switchboard and one from the emergency switchboard by separate feeders which should avoid galleys, machinery spaces and any other high risk areas and run to an automatic change-over switch situated near the sprinkler pump. The switch should allow power supply from the main switchboard until such time as failure occurs when automatic change-over to the emergency switchboard should take place. One of the sources of power supply for the alarm and detection system is to be an emergency source.

(ii) In cargo ships be connected to a main source of power supplied by at least two generators. The feeders should avoid galleys, machinery spaces and other high risk areas. One of the sources of supply for the alarm and detection system is to be an emergency source.

The sprinkler system should have a cross connection to the ship's fire main through a lockable screw down non-return valve. Means to test the automatic alarm and the automatic operation of the pump are to be provided together with spare sprinkler heads.

3.6 Halogenated Hydrocarbon Gas Systems (Halons)

3.6.1 Halon 1301 Systems

Bromotrifluromethane (BTM or Halon 1301) is acceptable for use in machinery spaces, pump rooms and in cargo spaces intended solely for the carriage of vehicles which are not carrying any cargo.

The quantity of halon required in cargo spaces intended solely for the carriage of vehicles which are not carrying any cargo should be based on the gross volume of the protected space in respect of the minimum concentration. For machinery spaces and pump rooms the quantity should be based on the gross volume of the protected space in respect of the maximum concentration including the casing. If in the event of fire the volume of free air in any air receiver could be released into the protected space an additional quantity of halon should be provided. The quantity of halon required is to be calculated in accordance with the following:

	Concentration	
	Minimum	Maximum
Cargo space	5%	7%
Machinery space and pump room	4·25%	7%

$$W = \frac{v}{s}\left(\frac{c}{100-c}\right)$$

where W = the weight of halon in kilogrammes.

v = the volume of the protected space in cubic metres.

s = the specific volume in cubic metres per kilogramme which equals $0.14781 + 0.000567t$ where t equals the temperature in degrees centigrade (normally assumed to be 20°C).

c = the volumetric concentration expressed as a percentage.

The two basic systems of Halon 1301 are stored as a liquid at normal temperature in:

(a) cylinders or spheres superpressurised with nitrogen to 25.3 kg/cm^2 or 42.2 kg/cm^2 to ensure rapid discharge of the halon.

(b) bulk in one or more tanks stored at its vapour pressure. A motive force of nitrogen stored at high pressure, is to be provided since the vapour pressure when stored in bulk would be insufficient to achieve the rapid discharge time required.

Discharge of halon into a protected space should be achieved in not more than 20 seconds except for local automatically operated units fitted in enclosed areas of high fire risk within machinery spaces where the discharge time should be not more than 10 seconds, based on the liquid phase. Because of the rapid discharge time required a detailed calculation to determine the optimum pipe diameters and nozzle sizes should be carried out.

Spaces such as purifier rooms, separator rooms and engine control rooms where separated from the engine room by steel bulkheads and doors should be considered part of the machinery space and be provided with pipes and nozzles from the main system. It should be ensured the quantity of halon for those spaces satisfies the maximum and minimum concentration requirements.

Because of its rapid rate of diffusion halon gas distribution nozzles are not required in the bilge areas.

Halon should be stored in containers or tanks designed, constructed and tested and marked in accordance with BS 5045 Part 1 or 2, or to an equivalent standard acceptable to a recognised national authority. They should be stamped with the weights when empty and full, the name of the contents, test pressure, date and place of testing and stamped by the official testing authority.

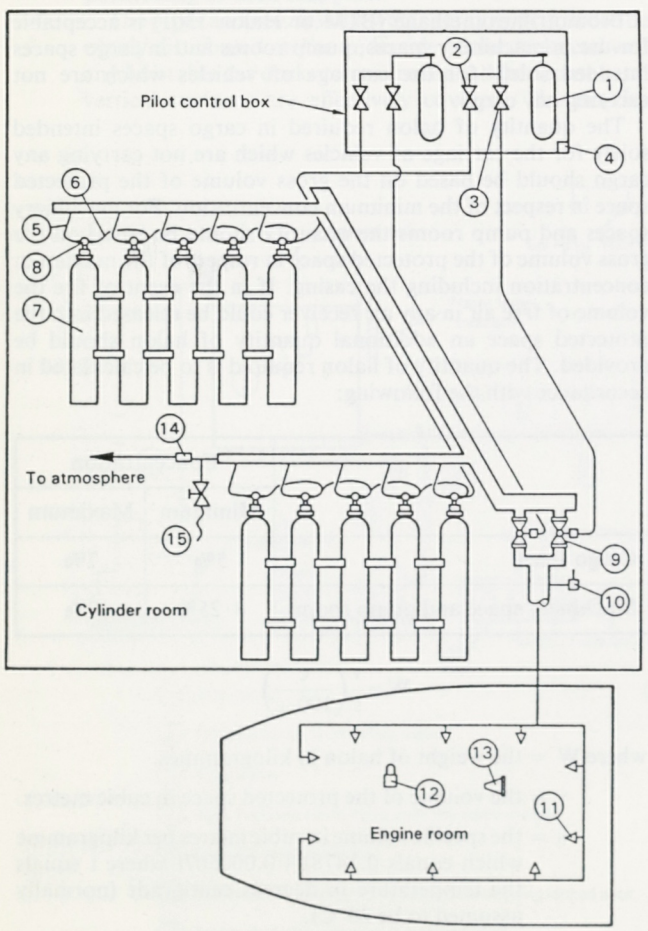
High pressure containers stored in banks outside the protected space are to be maintained and supported in racks and connected to a manifold generally by loops of flexible hose. Each cylinder head should be provided with valves which can be activated pneumatically or electrically and each valve connected to its neighbour by a flexible hose or electric cable. *See* Figure 5.

In bulk storage systems the main and distribution valves should be activated by the release of the nitrogen pressurising charge. *See* Figure 6.

A reliable means of indication is to be provided to check the contents in the containers and tanks. The storage temperature should not exceed 55 deg.C. Internal dip tubes are to be provided to ensure liquid halon is discharged from the container.

Distribution pipes should be of metallic construction not readily rendered ineffective by heat. Steel pipes are to be galvanised in areas where corrosion is likely to occur. Where there is a possibility of liquid halon entrapment in any section of pipework a suitable excess pressure relief device is to be fitted. Safety relief devices should also be positioned so that any discharge will not injure or endanger personnel. Drain traps are to be fitted in the lowest point in a pipework system if there is any possibility of accumulation of condensed water.

The discharge nozzles are to consist of the selected orifice and any associated shield, baffle or deflector. The nozzles should be manufactured in corrosion resistant material permanently marked to show the equivalent single orifice diameter. The design and type of nozzles selected and their positions are to be such that the required concentration when discharged into the



(1) 2.2 Kg pilot cylinder
(2) Selector valve to operate cylinders
(3) Selector valve to operate main pressure operated release valve arranged so that it cannot open before valve (2) is operated
(4) Door switch to operate alarms in engine room
(5) Flexible loop
(6) Pilot loop
(7) High pressure cylinder
(8) Pressure/manual actuator
(9) Pressure operated valve with switch
(10) Gas operated pressure switch to shut down E.R. vents
(11) Nozzle
(12) Rotating flashing lamp
(13) Horn or siren
(14) Pressure relief valve
(15) Compressed air connection

Fig. 5 Typical High Pressure Halon or CO_2 system

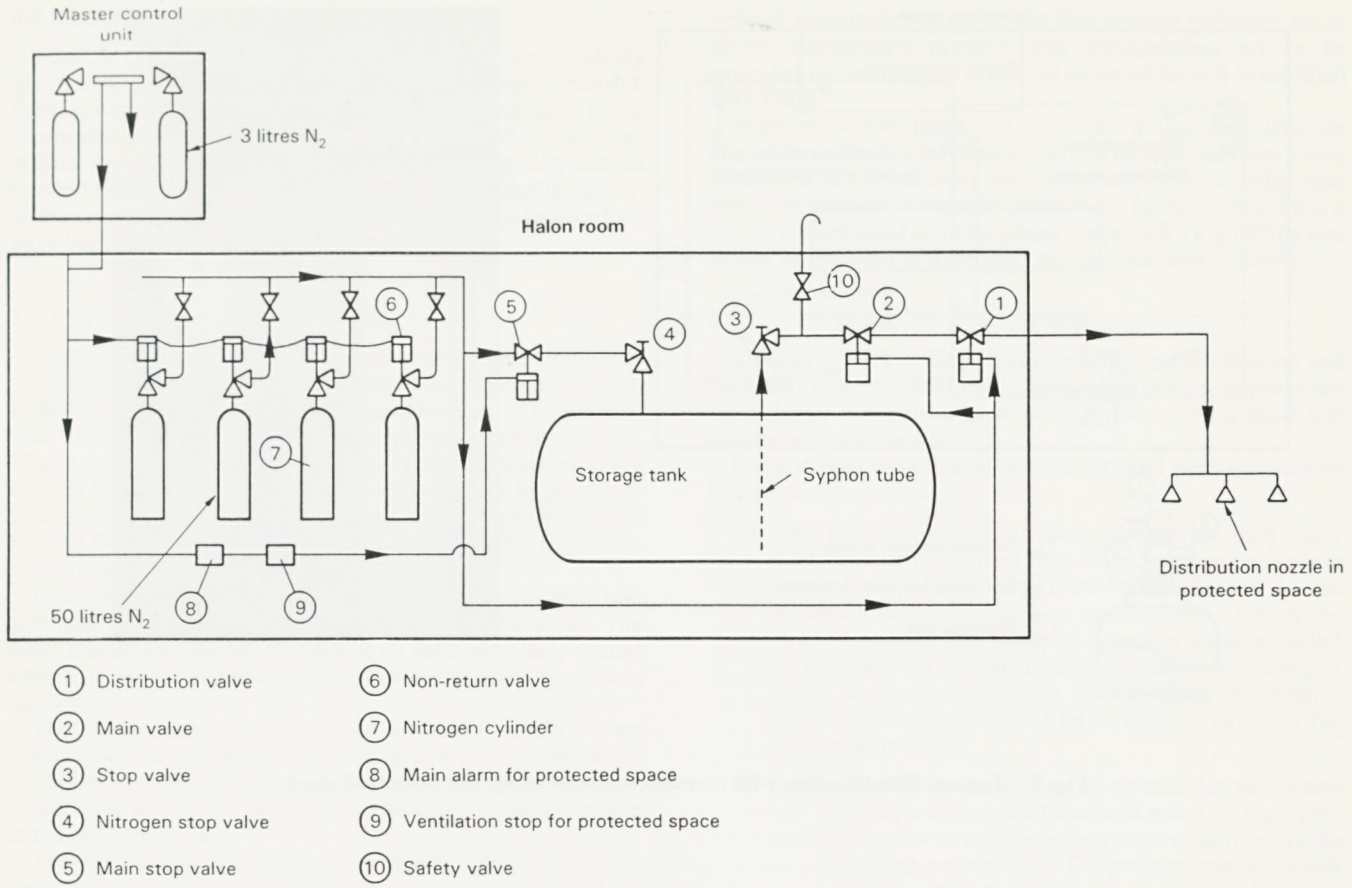


Fig. 6 Typical bulk Halon system

protected space will not unduly splash flammable liquids or create dust clouds which might extend the fire, create an explosion or otherwise adversely affect the contents of the enclosure.

The release mechanism should be simple to operate and incorporate a time delay, say 30 seconds, to ensure the personnel have time to evacuate the protected space before the gas is released. The controls are to include automatic means to stop the ventilation fans serving the space and for closing all openings before the halon is released. In oil tankers a notice is to be displayed at the controls for the release of gas into the cargo pump room stating that due to an electrostatic ignition hazard the system must only be used for fire extinguishing and not for inerting purposes. Simple and clear instructions for discharging the gas into each protected space should be prominently displayed at each release station.

Automatic audible warning of the release of halon is to be provided in each protected space. The warning should be a signal distinct from all other alarms and be audible in all parts of the protected space when all machinery and cargo pumps are operating at maximum power. If the warning is electrically operated it should be powered by batteries or through the emergency switchboard. In the cargo pump room air operated alarms are to be supplied with air that is clean and dry. Electrically operated alarms must be intrinsically safe with the operating mechanism located outside the pump room. Consideration should also be given to providing visual warning of the release of halon into machinery spaces and pump rooms since the wearing of protective ear muffs is common practice nowadays.

During installation of the system it should be ensured that the pipes and nozzles are in accordance with the approved plans since any deviation could seriously affect the flow characteristics and discharge time of the system.

If a system requires to be fully discharged for test purposes freon, which has similar discharge characteristics to halon and is very much less expensive, may be used.

3.6.1.1 Total Flooding System

The containers must be stored outside the protected space in an effectively ventilated and well lighted room situated in a safe and readily accessible position. Any entrance to the room should preferably be from the open deck. Access doors should open outwards and bulkheads and decks, including doors and other means of closing, are to be gastight where forming boundaries with adjoining enclosed spaces. Access from a protected space should not be permitted. Storage rooms are to be treated as "control stations" when applying the relevant fire integrity tables.

The medium should be delivered into the protected space through a simple system of pipes. The nozzles are to be located to ensure a uniform distribution of the medium throughout the protected space. In machinery spaces particular attention should be given to high risk areas, viz purifier, separator, generator, boiler and switchboard spaces.

The system is to be arranged for manual initiation of power release only, the controls being located in the storage room. Additional means could be provided for release from another position such as a fire control station or at an exit from the protected space. If the source of power is pneumatic two pilot gas bottles should be provided at the release station and if electric the second power source should be from an emergency generator or powered batteries.

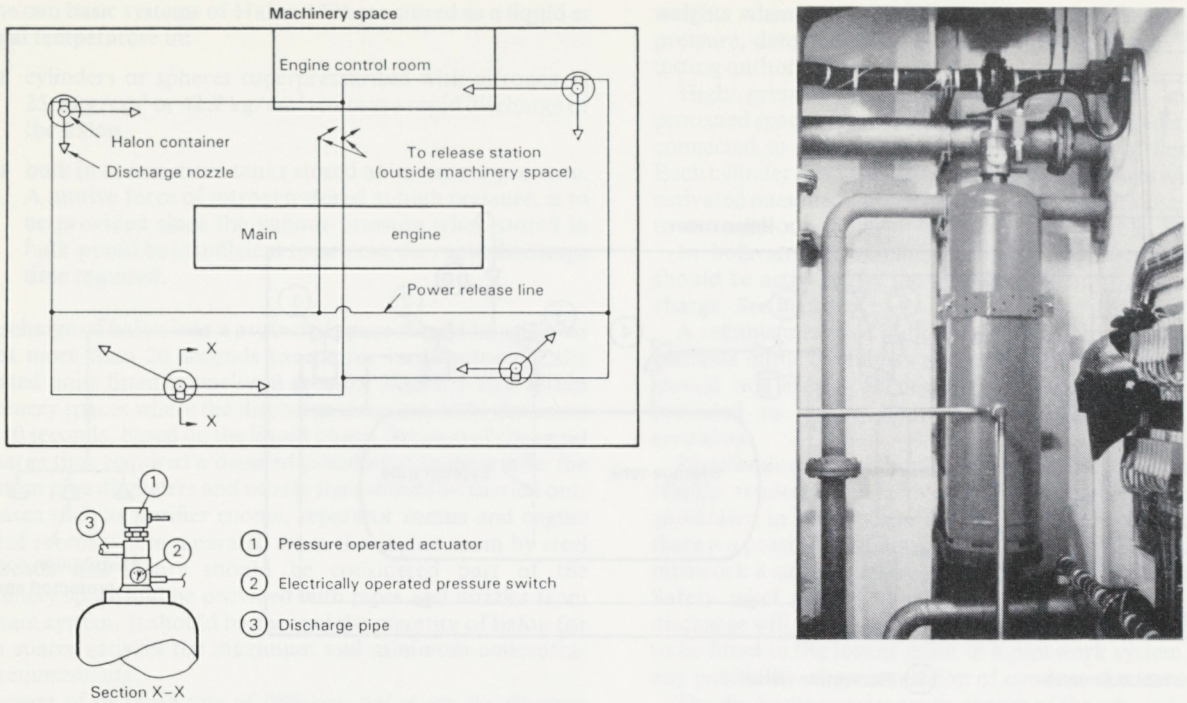


Fig. 7 Typical Halon system with containers stored inside the protected space

3.6.1.2 System with Individually Distributed Containers (*See* Figure 7).

Only machinery spaces and cargo spaces intended solely for the carriage of vehicles which are not carrying any cargo are permitted to have containers distributed therein and the system is to comply with the following:

(a) A manually initiated power release located in a readily accessible position outside the protected space is to be provided. Duplicate power sources are to be provided for the release, one of which may be located inside the protected space.

(b) Electric, pneumatic or hydraulic power circuits connecting the containers are to be monitored for fault conditions and loss of power. Visual and audible alarms in the fire control station or bridge are to be provided to indicate this.

(c) Within the protected space electric circuits or piping systems for the release of the system are to be heat resistant.

(d) An automatic overpressure device is to be fitted to each container which, in the event of exposure to the effects of fire and the system not being operated, will safely vent the contents into the protected space.

(e) The arrangement of containers and their release mechanisms is to be such that in the event of damage to any one power release line through fire or explosion in the protected space, i.e. a single fault concept, at least two thirds of the charge required for that space could still be discharged.

(f) Not more than two nozzles should be fitted to each container and their location should ensure a uniform distribution of the medium throughout the protected space.

(g) Any decrease in pressure is to be audibly and visibly indicated both in the protected space and at the control station.

3.6.1.3 Local Automatically Operated System

This system may only be fitted in enclosed areas of high fire risk within machinery spaces, in addition to and independent of any fixed fire extinguishing system, and should comply with the following:

(a) The space protected should preferably be on one working level and on the same level as the access. More than one working level could be included provided there is access at each level.

(b) The size of the space and arrangements of access and equipment should be such that escape from anywhere in the space could be effected in not more than 10 seconds.

(c) The operation of the system is to be signalled both visually and audibly outside each access to the space and at the release station for the system.

(d) A notice indicating that the space is protected by an automatically operated fire extinguishing system is to be displayed outside each access.

3.6.1.4 Automatically Operated System

This system should only be fitted in machinery spaces over equipment having a high fire risk in addition to and independent of any required fixed fire extinguishing system subject to 3.6.1.3 (c) and (d). The concentration is not to exceed 1.25% based on the gross volume of the machinery space.

3.6.2 Halon 1211 System

The use of Halon 1211 will be specially considered.

Containers with Halon 1211 should not be stored within a protected machinery space.

3.7 Foam Systems

Foam is suitable for use on Class B fires, i.e. fires involving flammable liquids or liquefiable solids. A fixed high expansion foam system may be fitted in machinery spaces and cargo pump rooms where accumulation of oil fuel and cargo oil could occur. A fixed low expansion system is to be used for fighting fires on the decks of ships carrying liquid cargoes of a flammable nature, such as may be caused by deck spillages or in cargo tanks which have been ruptured by collision or explosion.

3.7.1 High Expansion Foam System

High expansion foam is to be generated by units capable of rapidly discharging through fixed discharge outlets a quantity sufficient to fill the greatest space to be protected at a rate of at least 1 metre in depth per minute with a maximum filling time of 10 minutes. If the gross horizontal area of the protected space exceeds 400 m^2 at least two foam generators are to be provided. Sufficient foam concentrate is to be provided to produce foam for five fillings of the largest space protected. The expansion ratio of the foam should not exceed 1000 to 1.

Ducts should be made of steel or other suitable material and arranged to deliver the foam quickly to high risk areas. The ducts should include means, such as an automatic flap, so that a fire in the protected space will not affect the foam generating equipment.

The foam generator, its source of power supply, foam concentrate and means of controlling the system should be readily accessible, simple to operate and grouped in as few locations as possible at positions not likely to be cut off by fire in the protected space.

The water supply is to be from a source outside the protected space and could be from the emergency fire pump provided the capacity is sufficient to satisfy the requirements for the foam system and the demand for two hydrants (25 m^3/hr) at the required pressure.

High expansion foam will not flow against pressures much above atmospheric pressure and arrangements are to be provided for venting the protected space whilst it is being filled with foam.

High expansion foam has the disadvantage that once an engine room fire has developed it cannot be supplied from above because it is carried away by convection currents. Also heat radiation from above rapidly destroys the foam surface. Thus it can be argued that for a machinery space such a high filling rate would be required as to render this medium impracticable.

3.7.2 Low Expansion Foam System

The risk of deck spillage during loading and discharging and the rupture of the tanks by collision or explosion requires the entire cargo tanks deck area to be protected by a fixed low expansion foam system.

Foam should be delivered to monitors and hand applicators by one of two methods:

(a) The foam solution (i.e. foam concentrate with water added) is to be formed in a main foam control room located aft of the cargo tank area adjacent to the accommodation spaces in a position not likely to be made untenable by a fire in the spaces or areas protected by the system. The foam room is to contain the supply of foam concentrate, controls and ancillary equipment. The foam solution should be formed by either of the following methods:

(i) The foam concentrate pump and the main water pumps deliver the foam and water to a proportionator or proportioning eductor in roughly the correct proportions. The proportionator, which has a venturi and works on similar principles to a carburettor, should provide a fine adjustment of the mixture and make allowances for fluctuating supply conditions. (*See* Figure 8).

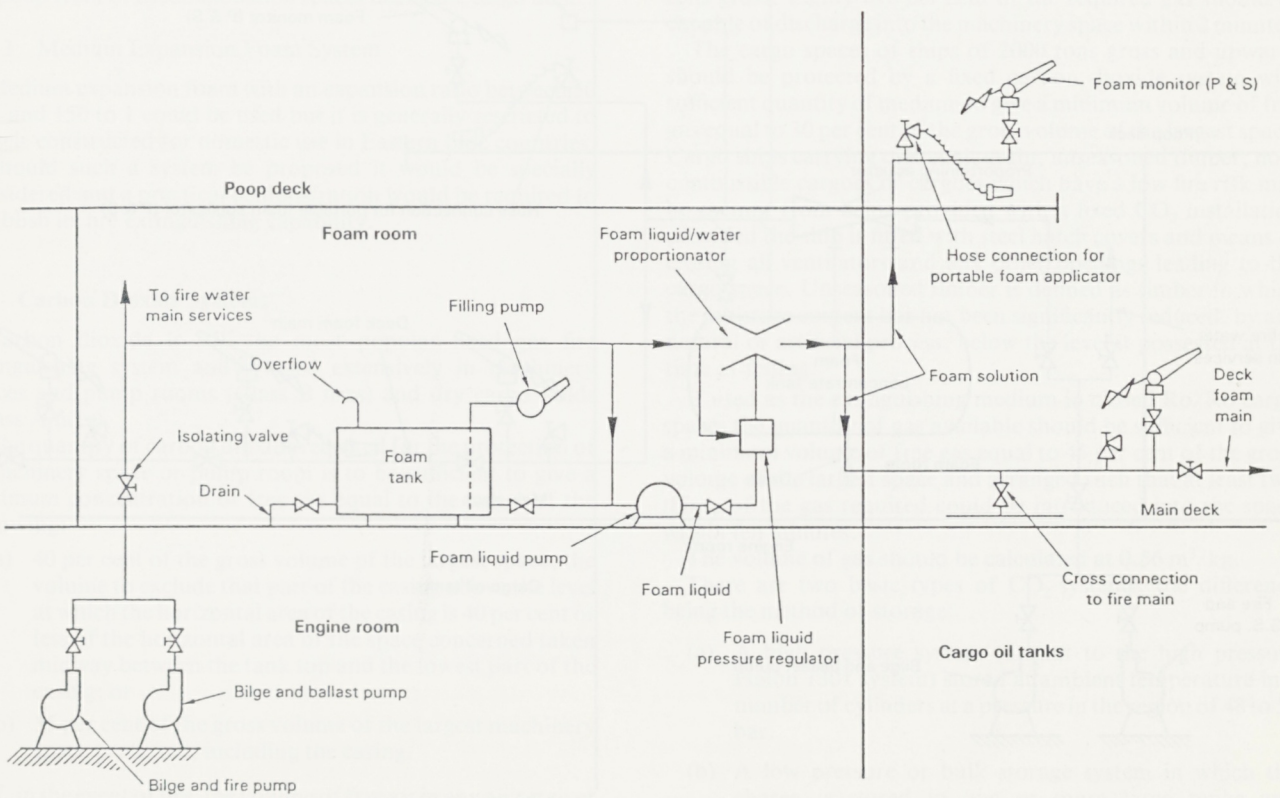


Fig. 8 Typical deck foam fire extinguishing system with proportionator

(ii) The water supplied from the main fire pumps educts the solution from the foam tank through the proportioning eductor before delivering the foam solution to the foam main. (*See* Figure 9).

The foam solution is delivered through a pipeline to monitors and hydrants located at intervals along the tank deck. Air is induced by the solution jet into the monitor barrels, or hand operated applicators, where expansion takes place and aerated foam is projected. The foam main must not be used for any other purpose. Isolating valves are to be provided in the foam main immediately forward of each monitor position. A cross connection to the fire main with an isolating valve should be provided.

(b) The foam concentrate is stored in the main foam control room located as (a) and delivered to the monitors and hydrants through a small diameter pipeline where it admixes with water supplied from the fire main, air is induced, expansion takes place and the aerated foam projected. Isolating valves are to be provided in the fire main immediately forward of each monitor position. (*See* Figure 10).

The deck foam system and the ships fire main system are to be capable of simultaneous operation in order that the personnel operating the foam fire fighting equipment may be cooled by water spray supplied from the fire main through a hose and nozzle. The main fire pumps should therefore have sufficient capacity to satisfy the requirements of the foam system and simultaneously provide two jets of water from the fire hydrants.

The rate of supply of foam solution is not to be less than the greater of the following:

(i) 0.6 litres/minute per square metre of cargo tanks deck area, where cargo tanks deck area means the maximum breadth of the ship multiplied by the total longitudinal extent of the cargo tank spaces;

(ii) 6 litres/minute per square metre of the horizontal sectional area of the single tank having the largest such area;

(iii) 3 litres/minute per square metre of the area protected by the largest monitor, such area being entirely forward of the monitor, but not less than 1250 litres/minute.

Sufficient foam concentrate at the above rates is to be supplied to ensure at least 20 minutes of foam generation in tankers fitted with inert gas systems and 30 minutes in tankers not fitted with inert gas systems. The foam expansion ratio should not exceed 12 to 1.

The number of monitors provided and their positions is to be such as to ensure that foam can be delivered to any part of the cargo tanks deck area. The distance from the monitor to the farthest extremity of the protected area forward of that monitor should not be more than 75 per cent of the monitor throw in still air conditions.

Applicators are to be provided to ensure flexibility of action and to cover areas screened by the monitors. The capacity of any applicator is not to be less than 400 litres/minute and the throw in still air conditions not less than 15 metres. Not less than four applicators are to be provided. Sufficient foam hydrants are to be provided to ensure that foam from at least two applicators can be directed to any part of the cargo tanks deck area.

Applicators may replace monitors in ships less than 4000 tonnes deadweight. The capacity of each applicator should be at least 25

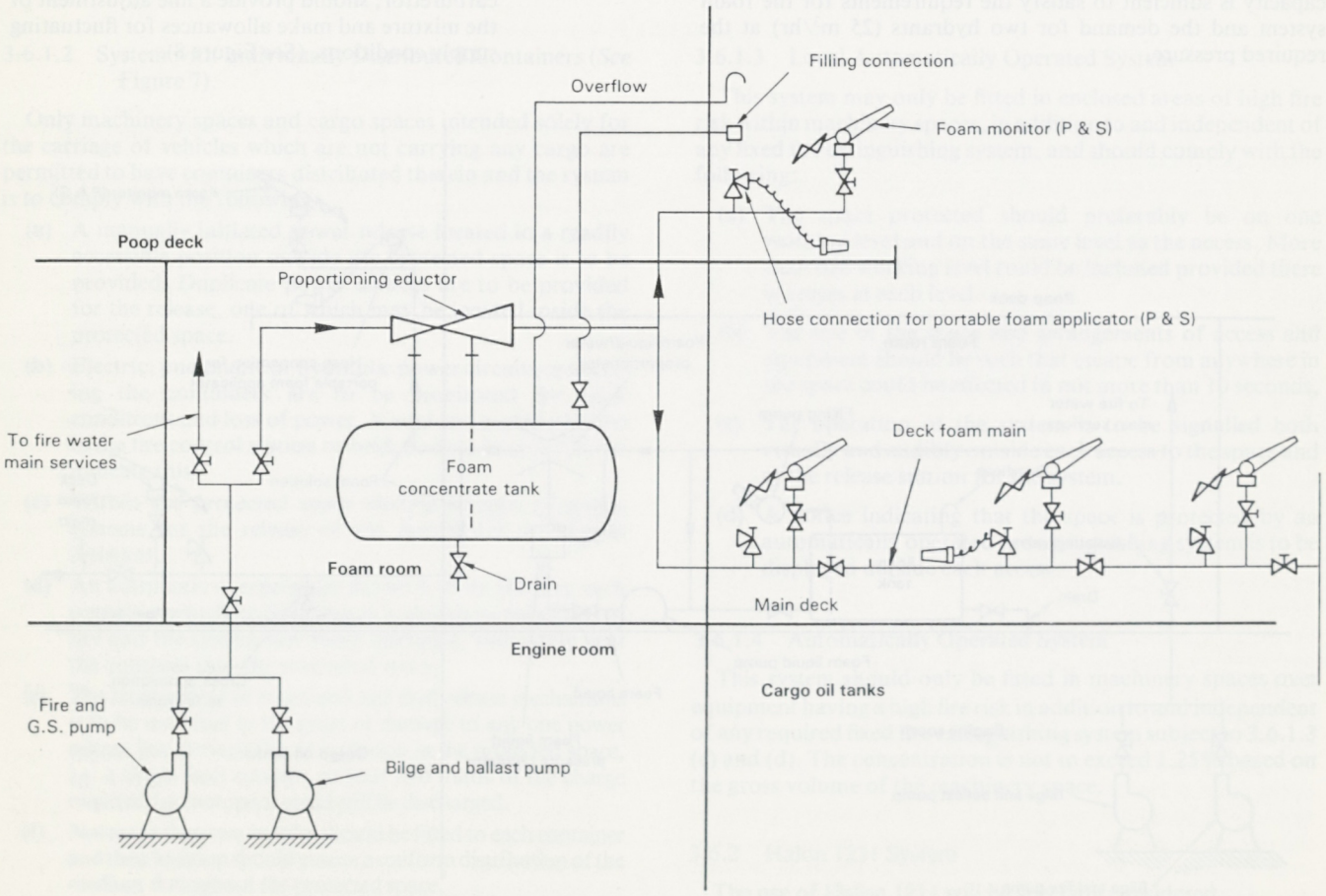


Fig. 9 Typical deck foam fire extinguishing system with proportioning eductor

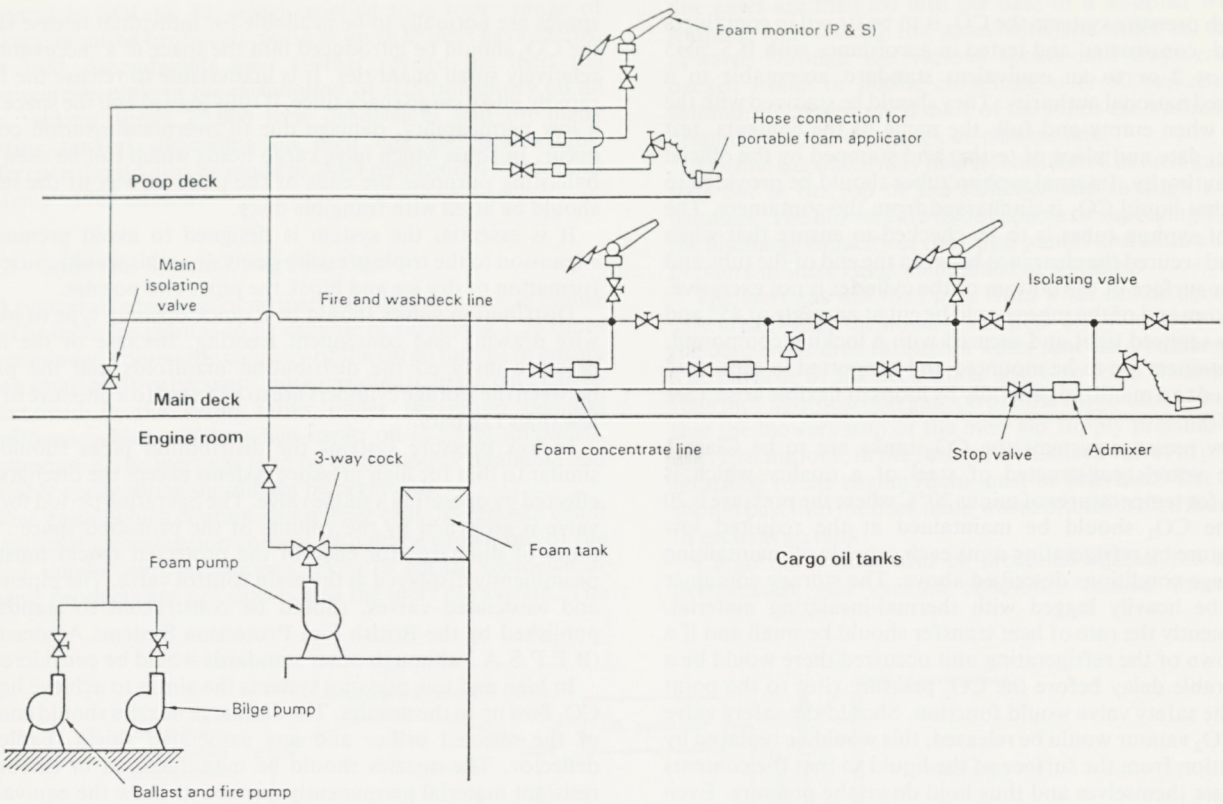


Fig. 10 Typical deck foam fire extinguishing system with admixer

per cent of the foam solution rate required by (a) or (b) above.

A monitor and hydrant is to be fitted both port and starboard at the poop front of accommodation spaces facing the cargo tank.

3.7.3 Medium Expansion Foam System

Medium expansion foam with an expansion ratio between 50 to 1 and 150 to 1 could be used but it is generally restricted to vessels constructed for domestic use in Eastern bloc countries.

Should such a system be proposed it would be specially considered and a practical demonstration would be required to establish its fire extinguishing capability.

3.8 Carbon Dioxide Systems

Carbon dioxide is still the most popular fixed gas fire extinguishing system and is used extensively in machinery spaces and pump rooms (Class B fires) and dry cargo holds (Class A fires).

The quantity of carbon dioxide required for the protection of a machinery space or pump room is to be sufficient to give a minimum concentration of free gas equal to the larger of the following:

(a) 40 per cent of the gross volume of the largest space, the volume to exclude that part of the casing above the level at which the horizontal area of the casing is 40 per cent or less of the horizontal area of the space concerned taken midway between the tank top and the lowest part of the casing; or

(b) 35 per cent of the gross volume of the largest machinery space protected, including the casing.

If, in the event of fire, the volume of free air in any air receiver could be released into the protected space then an additional quantity of CO_2 should be provided.

The above mentioned percentages may be reduced to 35 per cent and 30 per cent respectively for cargo ships of less than 2000 tons gross. Eighty five per cent of the required gas should be capable of discharge into the machinery space within 2 minutes.

The cargo spaces of ships of 2000 tons gross and upwards should be protected by a fixed carbon dioxide system with sufficient quantity of medium to give a minimum volume of free gas equal to 30 per cent of the gross volume of the largest space. Cargo ships carrying ore, coal, grain, unseasoned timber, non-combustible cargoes or cargoes which have a low fire risk may be exempt from being provided with a fixed CO_2 installation provided the ship is fitted with steel hatch covers and means of closing all ventilators and any other openings leading to the cargo space. Unseasoned timber is defined as timber in which the moisture content has not been significantly reduced, by any natural or artificial process, below the level it possessed at the time of felling.

If used as the extinguishing medium in closed Ro/Ro cargo spaces the quantity of gas available should be sufficient to give a minimum volume of free gas equal to 45 per cent of the gross volume of the largest space and arranged such that at least two thirds of the gas required could be introduced into the space within ten minutes.

The volume of gas should be calculated at 0.56 m^3/kg.

There are two basic types of CO_2 systems, the difference being the method of storage:

(a) A high pressure system (similar to the high pressure Halon 1301 system) stored at ambient temperature in a number of cylinders at a pressure in the region of 48 to 55 bar.

(b) A low pressure or bulk storage system in which the charge is stored in one or more large tanks and maintained at a pressure of about 20 bar by refrigeration.

In high pressure systems the CO_2 is to be stored in containers designed, constructed and tested in accordance with B.S.5045 Part 1 or 2 or to an equivalent standard acceptable to a recognised national authority. They should be stamped with the weights when empty and full, the name of the contents, test pressure, date and place of testing and stamped by the official testing authority. Internal syphon tubes should be provided to ensure that liquid CO_2 is discharged from the containers. The length of syphon tubes is to be checked to ensure that when fitted and secured the clearance between the end of the tube and the inner surface of the bottom of the cylinder is not excessive. The bottom end of the tube should be cut at an angle of 45° and the tube screwed tight and secured with a locking compound. The containers are to be mounted and supported in racks and connected to a manifold generally by loops of flexible hose. (*See* Figure 5.)

In low pressure systems the CO_2 tanks are to be Class 1 pressure vessels constructed of steel of a quality which is suitable for temperatures of minus 20°C where the pressure is 20 bar. The CO_2 should be maintained at the required low temperature by refrigerating units each capable of maintaining the storage conditions described above. The storage container should be heavily lagged with thermal-insulating material. Consequently the rate of heat transfer should be small and if a breakdown of the refrigerating unit occurred there would be a considerable delay before the CO_2 pressure rises to the point where the safety valve would function. Should the safety valve open, CO_2 vapour would be released; this would be replaced by evaporation from the surface of the liquid so that the contents refrigerate themselves and thus hold down the pressure. Even with summer temperatures it would be about 24 hours before any serious loss of gas occurs. However, this is an unlikely event in view of the duplication of power sources. The storage containers should be provided with relief devices and duplicate means of ascertaining the quantity of CO_2 which they contain. An automatic alarm is to be provided to indicate when 2 per cent of the contents have been lost. The alarm systems and one of the refrigerating units should be arranged to operate from two sources of power, one of which is to be the emergency source of electrical power. The discharge pipe should draw liquid CO_2 from the bottom of the tank. The outlet valve is to be a manually controlled stop valve.

The extinguishing medium should be stored outside the protected space in an effectively ventilated and well lighted room situated in a safe and readily accessible position. Any entrance to the room is preferably to be from the open deck. Access doors are to open outwards and bulkheads and decks, including doors and other means of closing, gastight where forming boundaries with adjoining enclosed spaces. Access from a protected space is not permitted. Storage rooms should be treated as "control stations" when applying the relevant fire integrity tables.

Distribution pipes should be of metallic construction not readily rendered ineffective by heat and galvanised steel pipes fitted in areas where corrosion is likely to occur. Where there is a possibility of liquid CO_2 entrapment a suitable pressure relief device is to be fitted. Safety relief devices should also be positioned so that any discharge will not injure or endanger personnel. Drain traps are to be fitted in the lowest point in the pipework system if there is any possibility of accumulation of condensed water.

The CO_2 should be delivered into the protected space through a simple system of pipes. The nozzles are to be located to ensure a uniform distribution of the medium throughout the protected space and in machinery spaces particular attention given to high risk areas; viz purifier, separator, generator, boiler and switchboard spaces. Generally most of the discharge should be distributed between the deckhead and the tank top but about 15 per cent of the required quantity of CO_2 is to be led to the bilge areas.

Those containers which are required to discharge to cargo spaces are normally to be available for individual release since the CO_2 should be introduced into the space in a succession of relatively small quantities. It is inadvisable to release the CO_2 rapidly into a cargo space since, if fully loaded and the space has a low permeability, damage due to overpressurisation could occur. In ships which have cargo holds which can be used for ballasting purposes the ends of the pipes in way of the holds should be fitted with frangible discs.

It is essential the system is designed to avoid premature expansion to the triple pressure point since this would cause the formation of dry ice and block the pipes and nozzles.

Distribution valves should be a quick opening type to avoid wire drawing and consequent freezing. Because of the high pressure involved the distribution manifolds and the pipes between the storage cylinders are to be tested to a pressure of not less than 122 bars.

In low pressure systems the distribution pipes should be similar to that for high pressure systems except the discharge is effected by operating a single valve. The operating period for the valve is governed by the volume of the protected space. The times of discharge for each of the protected spaces must be prominently displayed at the main control valve. The pipework and associated valves, should be constructed to standards published by the British Fire Protection Systems Association (B.F.P.S.A.) although other standards would be considered.

In high and low pressure systems the aim is to achieve liquid CO_2 flow up to the nozzles. The discharge nozzles should consist of the selected orifice and any associated shield, baffle or deflector. The nozzles should be manufactured in corrosion resistant material permanently marked to show the equivalent single orifice diameter. The design and type of nozzles selected and their positions is to be such that the required concentration when discharged into the protected space will not unduly splash flammable liquids or create dust clouds which might extend the fire or otherwise adversely affect the contents of the enclosure.

The release mechanism should be simple to operate and incorporate a time delay, say 30 seconds, to ensure the personnel have sufficient time to evacuate the protected space before the gas is released. The controls are also to include automatic means to stop ventilating fans serving the space and closing all openings before the CO_2 can be released. Simple and clear instructions for discharging the medium into each protected space must be prominently displayed at each control station. In oil tankers a notice should also be exhibited at the controls for the release of gas into the cargo pump room stating that due to the electrostatic ignition hazard, the system must only be used for fire extinguishing and not inerting purposes.

Audible warning of the release of CO_2 should be automatic and provided in each protected space. The warning is to be a signal distinct from all other alarms and be audible in all parts of the protected space with all machinery and cargo pumps operating at maximum power. If the warning is electrically operated it may be powered by batteries or through the emergency switchboard. In the cargo pump room air operated alarms may be used but the air supply should be clean and dry. Consideration should also be given to providing visual warning of the release of CO_2 into the machinery spaces and pump rooms since the wearing of protective ear muffs is common practice nowadays.

3.9 Inert Gas Systems

An inert gas system, where the inert gas is developed from boiler flue gases, was first installed on board an oil tanker in 1925 as a means of preventing explosions within the cargo tanks and remained voluntary until 1976. In 1974 IACS reached an agreed interpretation which became a unified requirement in 1976 and applied to crude oil tankers of 100 000 dwt and over and combination carriers of 50 000 dwt and over. The 1978

Protocol to SOLAS 74, which applied to a wider range of tankers, required further attention be given to inert gas systems. The 1981 Amendments have further revised the inert gas requirements making the installation of IGS obligatory on all new tankers above 20 000 tons deadweight and on many existing tankers depending on their age and deadweight. Reference should also be made to IMO publication "Inert Gas Systems" 1983 edition.

3.9.1 Inert Gas System Using Flue Gas

A typical arrangement of an inert gas plant is shown in Figure 11. The inert gas plant is to be capable of supplying 1.25 times the combined volumetric capacity of the cargo pumps to ensure that a small positive pressure, not exceeding 0.20 kg/cm^2, can be maintained in the cargo tanks under maximum demand conditions, which will be when cargo oil is being unloaded. Furthermore, the inert gas is to be continuously available and portable connections should not be permitted.

Flue gases, which contain about 5 per cent oxygen as a result of automatic combustion control, should be drawn out of the boiler uptake with precautions taken to ensure corrosive or erosive products are not drawn into the inert gas system. The flue gases are then led into the base of a scrubber where, by washing and cooling the gases with sea water as they pass upwards through the various sprays and trays containing packed stones or plastic chippings, over 90 per cent of the sulphurous contents and most of the solids are washed out and drained overboard through an effluent line.

The flue gas which may now be considered as inert gas, should pass out at the top of the scrubber and through a filter or demister. The blowers are to be capable of supplying 1.25 times the discharge capacity of the cargo pumps and ensure a positive pressure of inert gas is maintained at all times.

The inert gas will then pass from what can be considered a safe area (where the boilers, scrubber and fans are located) to the dangerous area through a water seal via a bulkhead valve. The purpose of the deck water seal is to form a barrier to the return of hydrocarbon gases from the cargo tanks in the event that the blowers stop or the inert gas supply pressure falls too low. Precautions, in the form of a balanced valve, to prevent oil returning to the engine room must be provided. The inert gas should pass into the deck main where branches distribute the gas to each cargo tank.

Cargo tanks must also be protected against the effects of overpressure and vacuum conditions caused either by the

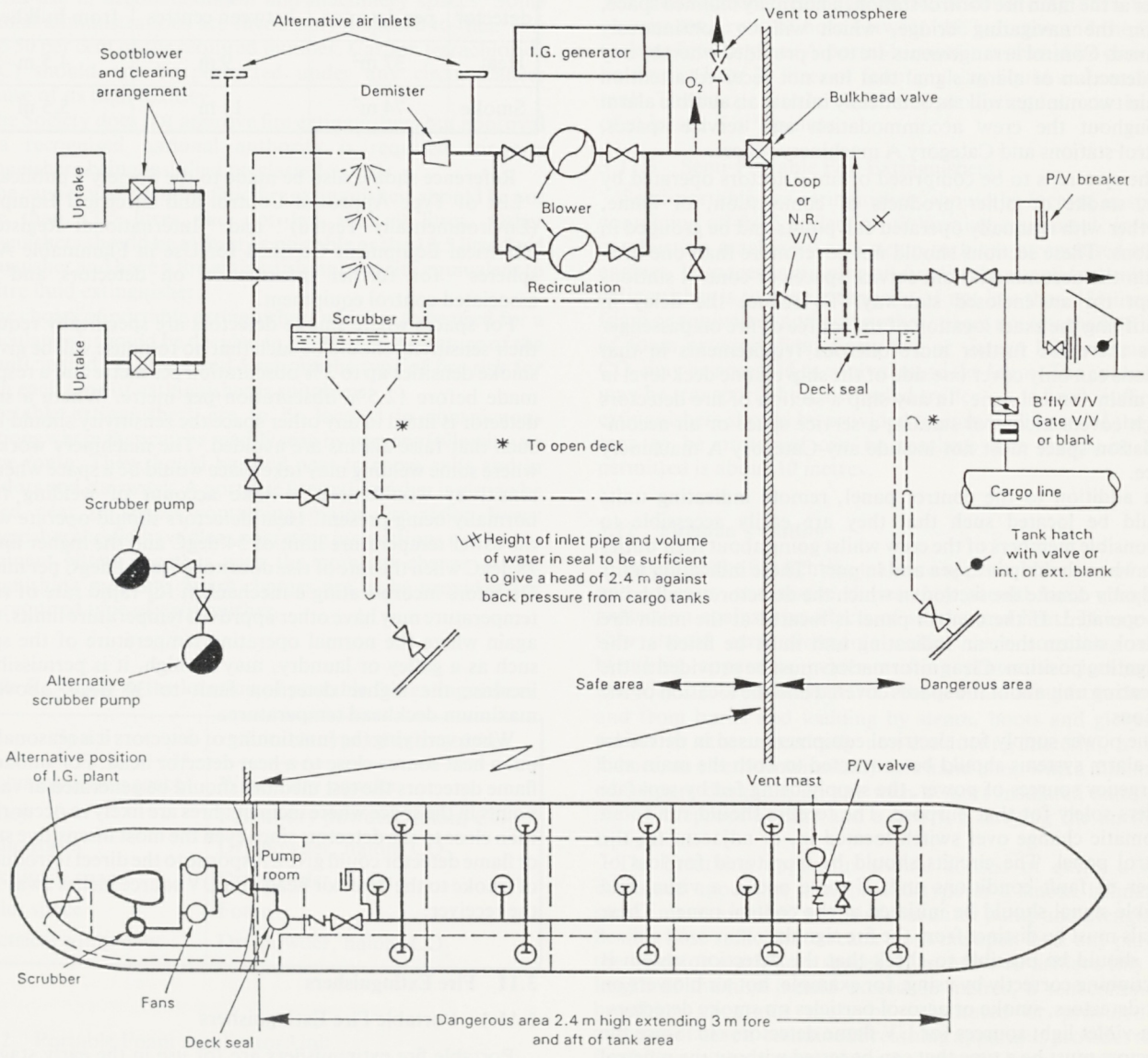


Fig. 11 Typical arrangement of inert gas system

loading, discharge, or transfer of cargo oil or by temperature variations during a voyage, and since inert gas must be carried under a small positive pressure up to 0.20 kg/cm^2 any breathing of the tanks must be through pressure/vacuum valves. During loading, when large volumes of hydrocarbon gases are emitted, a hand operated valve should be opened to allow the gases to escape up the vent mast to atmosphere by by-passing the pressure/vacuum valve.

A final safeguard against an excessive overpressure or vacuum condition in the cargo tanks is a pressure vacuum breaking device which should be fitted in the deck main.

3.9.2 Inert Gas System with Independent Generators

The system is similar to an inert gas system using flue gases from the boiler uptakes except that the gas is produced by units in which diesel oil is burnt under controlled conditions.

The units should be situated in compartments clear of the cargo tank deck.

3.10 Fixed Fire Detection and Fire Alarm System

The system is to be capable of immediate operation at all times and, on activation, is to give a visual and audible signal at the fire control panel. The fire control panel should be located either at the main fire control station, a normally manned space, or on the navigating bridge, which will be continuously manned. Control arrangements are to be provided whereby any fire detection or alarm signal that has not received attention within two minutes will automatically initiate an audible alarm throughout the crew accommodation and service spaces, control stations and Category A machinery spaces.

The system is to be comprised of fire detectors operated by heat, smoke or other products of combustion, or flame, together with manually operated call points and be grouped in sections. These sections should not cover more than one deck within the accommodation, service spaces or control stations except for an enclosed stairway. To reduce the delay in identifying the exact location of the source of fire on passenger ships there are further more onerous requirements in that sections can only cover one side of the ship on one deck level in one main vertical zone. In any ship a section of fire detectors which covers a control station, a service space or an accommodation space must not include any Category A machinery space.

In addition to the control panel, remote indicating units should be located such that they are easily accessible to responsible members of the crew whilst going about their duties both when the ship is at sea and in port. These indicating units need only denote the section in which the detector or call point has operated. If the control panel is located at the main fire control station then an indicating unit must be fitted at the navigating position. Clear information must be provided at the indicating unit about the spaces covered and the location of the sections.

The power supply for electrical equipment used in detection and alarm systems should be connected to both the main and emergency sources of power, the supply being fed by separate feeders solely for that purpose. The feeders should run to an automatic change over switch located in, or adjacent to, the control panel. The circuits should be monitored for loss of power or fault conditions and, if these occur, a visual and audible signal should be initiated at the control panel. These signals must be distinct from the fire signals.

It should be possible to check that the detection system is functioning correctly by using, for example, hot air blowers on heat detectors, smoke or aerosol particles on smoke detectors, ultra-violet light sources for UV flame detectors etc. Since the detectors must be a type that can be tested without the renewal of any component, then systems using, for example, fusible plugs would not be acceptable for this type of system.

Smoke detectors are required to be installed in all stairways, corridors and escape routes within accommodation spaces except as provided otherwise in Method III(c) in section 4.2. and should also be fitted in selected parts of the ventilation trunking. For other spaces where a detection system is required the detectors may be of the heat, smoke or flame detection type as best suited for the type of incipient fire to be expected and at least one detector should be fitted in each space.

Detectors are to be located for optimum performance and factors such as the effect of ventilation air movement on smoke detectors, structural overhangs containing hot layers of combustion products and equipment interfering with the "line of sight" of flame detectors must all be taken into consideration. Both the selection of the right type of detector for the fire hazard of the space and its correct location have been previously addressed in detail in the LRTA paper "Fire Detection in Unattended Machinery Spaces" by J. D. Bolding to which reference should be made for more information concerning these aspects. A limitation on the maximum spacing of detectors has, however, been established and should not be exceeded unless adequate tests have been carried out to establish other characteristics for the particular detector concerned.

Type of detector	Max. floor area per detector	Max. distance apart between centres	Max. distance away from bulkheads
Heat	37 m^2	9 m	4.5 m
Smoke	74 m^2	11 m	5.5 m

Reference should also be made to the Society's publications "List of Type Approved Control and Electrical Equipment (Environmentally Tested)" and "International Register of Electrical Equipment Certified for Use in Flammable Atmospheres" for further information on detectors and their associated control equipment.

For spaces where smoke detectors are specifically required, their sensitivity should be such that no response will be given to smoke densities up to 2% obscuration per metre and a response made before 12.5% obscuration per metre. Where a smoke detector is fitted in any other space the sensitivity should be set such that false alarms are avoided. The machinery workshop where some welding may take place would be a space where the sensitivity would need to take account of welding fumes normally being present. Heat detectors should operate within the lower temperature limit of 54 degC and the higher limit of 78 degC when the rate of rise does not exceed 1 degC per minute. Detectors incorporating a mechanism for rapid rate of rise in temperature may have other approved temperature limits. Once again where the normal operating temperature of the space, such as a galley or laundry, may be high, it is permissible to increase the higher detection limit to 30 degC above the maximum deckhead temperature.

When verifying the functioning of detectors it is reasonable to put a heat source close to a heat detector head. For smoke and flame detectors the test medium should be generated at various points in the space where incipient fires are likely to occur rather than close to the detector; since even the most insensitive smoke or flame detector could give a response to the direct introduction of smoke to the detector head or a UV source inches away from the receiver.

3.11 Fire Extinguishers

3.11.1 Portable Fire Extinguishers

Portable fire extinguishers are for use in the early stages of fire when their portability and immediate availability for use by one person enable a prompt attack to be made. They should not

Table 4 Portable fire extinguishers

Type	Type of fire for which suited	Suitability for fires involving electrical equipment	Capacity for ship use	Colour coding
Water	A	No	9 litres (2 gallons)	Signal Red
Foam	B	No	9 litres (2 gallons)	Pale Cream
Dry powder	ABC	Yes	3 kg (7 lb)	French Blue
BCF (Halon 1211)	BC	Yes	1.5 kg (3 lbs)	Emerald Green
BCM (Halon 1301)	BC	Yes	1.5 kg (3 lbs)	Emerald Green
CO_2	BC	Yes	2.3 kg (5 lbs)	Black

N.B. Type D fires require a specially suited dry powder. The above types could cause an explosion when used on fires involving some metals.

be expected to deal with a large fire since they are essentially first aid fire fighting appliances of limited capacity.

Portable fire extinguishers may be divided into five categories according to the extinguishing agent they contain namely water, foam, dry powder, halogenated hydrocarbon and carbon dioxide.

Halon extinguishers are not encouraged by the Society for general use in accommodation and machinery spaces. Some national administrations are favourably disposed to their use; up to 50 per cent of the required number. Carbon tetrachloride (CTC) should not be permitted under any circumstances because of its high toxicity.

The Society does not approve fire extinguishers but approval by a recognised national authority is required for any extinguishers being installed on classed vessels.

The capacity of portable fluid fire extinguishers should be not more than 13.5 litres and not less than 9 litres. Other extinguishers should be at least as portable as the 13.5 litre fluid extinguisher and have a fire extinguishing capacity equivalent to a 9 litre fluid extinguisher.

The choice of portable extinguishers which is to be used for a particular risk should be decided in relation to the nature of the fire anticipated. Tables 4 and 5 set out the type of fire risk for which each type of extinguisher is suitable.

Portable extinguishers are to be located in conspicuous positions where they can be readily seen by persons following an escape route. They should be sited near to room exits and in corridors and stairways. A portable fire extinguisher is also to be stowed near to spaces containing major fire risks. Every extinguisher should have clear operating instructions marked in prominent letters together with the nominal charge of the extinguishing medium. Spare charges are to be provided for each required type of extinguisher.

Table 5 Guide to the location of portable fire extinguishers

Space	Suitable type of extinguisher
Accommodation space	Water, dry powder
Galley	Foam, dry powder, halon, CO_2
Radio room	Dry powder, halon, CO_2
Machinery space	Dry powder, foam
Boiler space	Foam
Electrical equipment	Dry powder, halon, CO_2

3.11.2 Portable Foam Applicator Unit

Portable foam applicator units should be provided in spaces containing oil-fired boilers or oil fuel units, internal combustion machinery, special category spaces and in Ro/Ro cargo spaces intended for the carriage of motor vehicles with fuel in their tanks for their own propulsion. In the cargo spaces there should be a unit provided in each space with one additional unit available on board the ship.

The unit should consist of an air foam nozzle of an inductor type and be capable of connection to the fire main by a fire hose. The pressure drop through an inductor is only 25% which permits long runs of hose between the inductor and the foam making branch pipe. A portable container should be provided holding at least 20 litres of foam making liquid and one spare tank. The nozzle is to be capable of producing foam at the rate of at least 1.5 m^3/minute.

3.11.3 Semi-Portable Fire Extinguishers

Semi-portable fire extinguishers should be located in spaces containing oil-fired boilers or oil burning equipment, internal combustion machinery and steam turbines or enclosed steam engines. In spaces containing oil-fired boilers or oil fuel units the extinguisher is to have a capacity of not less than 135 litres of foam or equivalent and in the other spaces not less than 45 litres of foam or equivalent. Forty-five or sixteen kilogrammes of CO_2 may be accepted as equivalent to the foam. The containers may be transported on a wheeled trolley or, if fixed, sufficient extinguishers should be provided to ensure all parts of the risk area to be protected can be reached. The length of hose permitted is about 10 metres.

3.12 Fireman's Outfits

To enable the fire fighting teams to approach the seat of a fire and to carry out rescue duties they should have adequate protection against the effects of smoke and heat. Thus every ship should carry fireman's outfits each consisting of a breathing apparatus, water-resisting protective clothing of material to protect the skin from the heat radiating from the fire and from burns and scalding by steam, boots and gloves of rubber or other electrically non-conducting material, a rigid helmet, an electric intrinsically safe hand lamp with a minimum of 3 hours duration, an axe with a short insulated handle, a strong fireproof lifeline and a belt for carrying the ancillary equipment.

The breathing apparatus should consist of either a self-contained apparatus of approved type or a smoke helmet or smoke mask, supplied with air from an air pump and a length of flexible hose sufficient to reach from the open deck any part of the holds or machinery spaces. If in order to achieve this the length of the hose would exceed 36 metres, a self-contained breathing apparatus must be substituted or provided in addition. The self-contained breathing apparatus provides total flexibility to the wearer, whereas, the air hose is subject to damage, restricts the wearers mobility and is dependent on a second person supplying the air to the user.

The self-contained breathing apparatus has various designs of equipment but the basic principle is the same for all types. The apparatus should consist of a face mask attached by a flexible hose to one or two cylinders containing air and supported on a frame and harness. The capacity of the apparatus is to be not less than 1200 litres to give a nominal functioning time of 30 minutes, but this depends on the breathing rate of the user.

The arrangement of a typical apparatus should be as follows:

(i) The cylinders are connected to a reducing valve which reduces the pressure of the air passing through to about 4 bars. The air then passes through a "demand valve" which further reduces the pressure and passes air to the wearer as he inhales and closes when he exhales. An automatic valve releases exhaled air from the face mask. A by-pass valve is provided for use in emergencies and permits air to be supplied to the mask without passing through the reducing valve. The by-pass valve is adjusted by hand to give the rate of supply; it must, of course, be used judiciously, because an injudicious increase in the rate of flow will greatly reduce the operating time of the set. The function of the two valves may be replaced by a single demand valve where this is located in the face mask and the by-pass valve is then omitted.

(ii) When about 10 minutes air supply remains in the cylinder a whistle sounds continuously, warning the user.

(iii) The face mask is made of moulded rubber with a series of adjustable rubber straps to secure it to the head of the wearer and fitted with quick release arrangements. The visor should have a good field of vision so that the wearer does not need to turn his head constantly.

(iv) A gauge should be provided to indicate the pressure of the air in the cylinder.

(v) Spare cylinders should be provided for each self-contained breathing apparatus. The provision of a small air compressor to charge the cylinders is to be encouraged.

(vi) Equipment using compressed oxygen or closed circuit regenerative apparatus is not acceptable for use on board ships.

(vii) All ships, irrespective of age, should carry at least two fireman's outfits. Passenger ships and tankers, irrespective of age, have additional requirements for fireman's outfits.

4. FIRE PROTECTION

4.1 Passenger Ships

4.1.1 Structure

The hull, superstructure, decks and deck houses are required to be constructed of steel or other equivalent material. The use of aluminium alloy is permissible in the construction, however, due to its low melting point and resultant loss of structural integrity when exposed to fire, the following limitations are imposed on its use:

(i) The insulation of aluminium alloy components of "A" or "B" class divisions, except structure which is non-load-bearing, should be such that the temperature of the structural core does not rise more than 200 degC above the ambient temperature at any time during the applicable fire exposure to the standard fire test, ("A-class" 1 hour, "B-class" 30 minutes).

(ii) Special attention should be given to the insulation of aluminium alloy components of columns, stanchions and other structural members required to support lifeboat and liferaft stowage, launching and embarkation areas, and "A" and "B" class divisions to ensure that for such members supporting lifeboat and liferaft areas and "A" class divisions, the temperature rise limitation specified applies at the end of one hour. For such members required to support "B" class divisions, the temperature rise limitation specified applies at the end of half an hour.

The crowns and casings of machinery spaces of Category A should be of steel construction and adequately insulated in accordance with Tables 6 and 7.

4.1.2 Main Fire Zones

(i) (More than 36 passengers)

In order to confine any outbreak of fire to proportions which will provide a reasonable possibility of achieving its extinction and, furthermore, to facilitate the escape of the passengers and crew from their accommodation at all levels to the embarkation deck, the hull, superstructure and deckhouses are subdivided into main vertical fire zones by bulkheads spaced not more than 40 metres apart. These bulkheads must extend from deck to deck and to the shell or other steel boundaries. They should generally be in the same vertical line from the tank top to the topmost deck. Below the level of the bulkhead deck, the watertight sub-division bulkheads may also serve as main fire zone bulkheads and above that level the main fire zone bulkheads should, as far as practicable, follow the same vertical line. Where this is impracticable the bulkhead may be stepped, although such steps and recesses should be kept to a minimum.

On ships designed for special purposes, such as car or train ferries where the installation of vertical zone bulkheads would defeat the purpose of the ship, such bulkheads may be dispensed with in the car or train deck spaces and the latter treated as horizontal zones.

The main horizontal or vertical zones may require fire insulation but this depends on the nature of the fire risk in the adjacent spaces. A bulkhead, for example, separating two toilet spaces where the fire risk is low would not require as high a standard of insulation as one separating a fire control station from a vehicle deck. The insulation requirements are set out in Tables 6a and 6b for bulkheads and decks respectively. It will be noted that in some instances two values are given for the insulation values. Where both adjacent spaces are protected by a sprinkler system then the lower insulation value may be used, whereas if only one space, or neither, is protected by a sprinkler system then the higher insulation value is to be used.

In addition to the main zone boundaries, a table of fire integrity and insulation values has also been established for the boundaries of adjacent spaces within the main zones. These are shown in Tables 6c and 6d. The integrity standard and insulation value are in each case dependent on the nature of the fire risk of the adjacent spaces and once again on whether a sprinkler system is fitted or not.

The purpose of these fire divisions is to contain any outbreak of fire long enough for it to be detected and the fire crew mobilised to limit its spread and put it out. It will also be necessary for the passengers and crew in the immediate vicinity to make a safe escape. It will be noted that, in this respect, all stairway enclosures are to be A class, corridors in the accommodation area leading to stairways B class and corridors in other parts of the

vessel A class. In corridors and stairways forming escape routes, both exposed and concealed surfaces of the linings of fire divisions are to have low surface spread of flame characteristics if they are faced with combustible veneers or laminates. Even painted steel should have low flame spread characteristics in these areas.

(ii) (Up to 36 passengers)

The requirement to divide the ship into main vertical zones spaced not more than 40 metres apart is also applied to this type of ship and similarly this requirement may be modified for vehicle or train deck spaces to use horizontal zones.

The exact requirements for bulkheads and decks separating adjacent spaces are given in Tables 7a and 7b, there being no differentiation in this case for divisions forming main zones or not. The underlying principles in the formulation of the tables is the same as that for passenger ships carrying more than 36 passengers.

Since any fire division can only be as good as its weakest part, then all penetrations such as doors, ventilation trunks, pipes and electric cables must be of equivalent fire integrity to that of the division they penetrate.

Tables 6(a) to (d) Classification of spaces according to fire risk

The number in parentheses preceding each category refers to the applicable column or row number in the Tables.

(1) *Control stations*
Spaces containing emergency sources of power and lighting.
Wheelhouse and chartroom.
Spaces containing the ship's radio equipment.
Fire-extinguishing rooms, fire control and recording stations.
Control room for propulsion machinery when located outside the propulsion machinery space.
Spaces containing centralized fire alarm equipment.
Spaces containing centralized emergency public address system stations and equipment.

(2) *Stairways*
Interior stairways, lifts and escalators (other than those wholly contained within the machinery spaces) for passengers and crew and enclosures thereto.
In this connexion, a stairway which is enclosed at only one level shall be regarded as part of the space from which it is not separated by a fire door.

(3) *Corridors*
Passenger and crew corridors and lobbies.

(4) *Lifeboat and liferaft handling and embarkation stations*
Open deck spaces and enclosed promenades forming lifeboat and liferaft embarkation and lowering stations.

(5) *Open deck spaces*
Open deck spaces and enclosed promenades clear of lifeboat and liferaft embarkation and lowering stations.
Air space (the space outside the superstructures and deckhouses).

(6) *Accommodation spaces of minor fire risk*
Cabins containing furniture and furnishings of restricted fire risk.
Offices and dispensaries containing furniture and furnishings of restricted fire risk.
Public spaces containing furniture and furnishings of restricted fire risk and having a deck area of less than 50 m^2.

(7) *Accommodation spaces of moderate fire risk*
Spaces as in category (6) above but containing furniture and furnishings of other than restricted fire risk.
Public spaces containing furniture and furnishings of restricted fire risk and having a deck area of 50 m^2 or more.
Isolated lockers and small store-rooms in accommodation spaces.
Sale shops.
Motion picture projection and film stowage rooms.
Diet kitchens (containing no open flame).
Cleaning gear lockers (in which flammable liquids are not stowed).
Laboratories (in which flammable liquids are not stowed).
Pharmacies.
Small drying rooms (having a deck area of 4 m^2 or less).
Specie rooms.

(8) *Accommodation spaces of greater fire risk*
Public spaces containing furniture and furnishings of other than restricted fire risk and having a deck area of 50 m^2 or more.
Barber shops and beauty parlours.

(9) *Sanitary and similar spaces*
Communal sanitary facilities, showers, baths, water closets, etc.
Small laundry rooms.
Indoor swimming pool area.
Operating rooms.
Isolated pantries containing no cooking appliances in accommodation spaces.
Private sanitary facilities shall be considered a portion of the space in which they are located.

(10) *Tanks, voids and auxiliary machinery spaces having little or no fire risk*
Water tanks forming part of the ship's structure.
Voids and cofferdams.
Auxiliary machinery spaces which do not contain machinery having a pressure lubrication system and where storage of combustibles is prohibited, such as:
ventilation and air-conditioning rooms; windlass room; steering gear room; stabilizer equipment room; electrical propulsion motor room; rooms containing section switchboards and purely electrical equipment other than oil-filled electrical transformers (above 10 kVA); shaft alleys and pipe tunnels; spaces for pumps and refrigeration machinery (not handling or using flammable liquids).
Closed trunks serving the spaces listed above.
Other closed trunks such as pipe and cable trunks.

(11) *Auxiliary machinery spaces, cargo spaces, special category spaces, cargo and other oil tanks and other similar spaces of moderate fire risk*
Cargo oil tanks.
Cargo holds, trunkways and hatchways.
Refrigerated chambers.
Oil fuel tanks (where installed in a separate space with no machinery).
Shaft alleys and pipe tunnels allowing storage of combustibles.
Auxiliary machinery spaces as in Category (10) which contain machinery having a pressure lubrication system or where storage of combustibles is permitted.
Oil fuel filling stations.
Spaces containing oil-filled electrical transformers (above 10 kVA).
Spaces containing turbine and reciprocating steam engine driven auxiliary generators and small internal combustion engines of power output up to 110 kW driving emergency generators, sprinkler, drencher or fire pumps, bilge pumps, etc.
Special category spaces (Tables 6a and 6b only apply).
Closed trunks serving the spaces listed above.

(12) *Machinery spaces and main galleys*
Main propulsion machinery rooms (other than electric propulsion motor rooms) and boiler rooms.
Auxiliary machinery spaces other than those in categories (10) and (11) which contain internal combustion machinery or other oil-burning, heating or pumping units.
Main galleys and annexes.
Trunks and casings to the spaces listed above.

(13) *Store-rooms, workshops, pantries, etc.*
Main pantries not annexed to galleys.
Main laundry.
Large drying rooms (having a deck area of more than 4 m^2). Miscellaneous stores.
Mail and baggage rooms.
Garbage rooms.
Workshops (not part of machinery spaces, galleys, etc.).

(14) *Other spaces in which flammable liquids are stowed*
Lamp rooms.
Paint rooms.
Store rooms containing flammable liquids (including dyes, medicines, etc.).
Laboratories (in which flammable liquids are stowed).

Table 6a Bulkheads bounding main vertical zones or horizontal zones; passenger ships carrying more than 36 passengers

Spaces		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Control stations	(1)	A-60	A-30	A-30	A-0	A-0	A-60	A-60	A-60	A-0	A-0	A-60	A-60	A-60	A-60
Stairways	(2)		A-0	A-0	A-0	A-0	A-15 A-0	A-30 A-0	A-60 A-15	A-0	A-0	A-30	A-60	A-15 A-0	A-60
Corridors	(3)			A-0	A-0	A-0	A-0	A-30 A-0	A-30 A-0	A-0	A-0	A-30	A-60	A-15 A-0	A-60
Lifeboat and liferaft handling and embarkation stations	(4)				—	—	A-0	A-0	A-0	A-0	A-0	A-0	A-60	A-0	A-60
Open deck spaces	(5)					—	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Accommodation spaces of minor fire risk	(6)						A-15 A-0	A-30 A-0	A-30 A-0	A-0	A-0	A-15 A-0	A-30	A-15 A-0	A-30
Accommodation spaces of moderate fire risk	(7)							A-30 A-0	A-60 A-15	A-0	A-0	A-30 A-0	A-60	A-30 A-0	A-60
Accommodation spaces of greater fire risk	(8)								A-60 A-15	A-0	A-0	A-60 A-15	A-60	A-30 A-0	A-60
Sanitary and similar spaces	(9)									A-0	A-0	A-0	A-0	A-0	A-0
Tanks, voids and auxiliary machinery spaces having little or no fire risk	(10)										A-0	A-0	A-0	A-0	A-0
Auxiliary machinery spaces, cargo spaces, special category spaces, cargo and other oil tanks and other similar spaces of moderate fire risk	(11)											A-0	A-60	A-0	A-60
Machinery spaces and main galleys	(12)												A-60	A-30[b] A-15	A-60
Store-rooms, workshops, pantries, etc.	(13)													A-0	A-30
Other spaces in which flammable liquids are stowed	(14)														A-60

See notes under Table 6d.

Table 6b Decks forming steps in main vertical zones or bounding horizontal zones; passenger ships carrying more than 36 passengers

Space below ↓ Space above →		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Control stations	(1)	A-60	A-60	A-30	A-0	A-0	A-15	A-30	A-60	A-0	A-0	A-30	A-60	A-15	A-60
Stairways	(2)	A-15	A-0	A-0	A-0	A-0	A-0	A-15 A-0	A-15 A-0	A-0	A-0	A-0	A-60	A-0	A-60
Corridors	(3)	A-30	A-0	A-0	A-0	A-0	A-0	A-15 A-0	A-15 A-0	A-0	A-0	A-0	A-60	A-0	A-60
Lifeboat and liferaft handling and embarkation stations	(4)	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Open deck spaces	(5)	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Accommodation spaces of minor fire risk	(6)	A-60	A-30 A-0	A-15 A-0	A-0	A-0	A-0	A-15 A-0	A-30 A-0	A-0	A-0	A-15 A-0	A-15	A-0	A-15
Accommodation spaces of moderate fire risk	(7)	A-60	A-60 A-15	A-30 A-0	A-15 A-0	A-0	A-15 A-0	A-30 A-0	A-60 A-15	A-0	A-0	A-30 A-0	A-30	A-0	A-30
Accommodation spaces of greater fire risk	(8)	A-60	A-60 A-15	A-60 A-15	A-60 A-15	A-0	A-30 A-0	A-60 A-15	A-60 A-15	A-0	A-0	A-30 A-0	A-60	A-15 A-0	A-60
Sanitary and similar spaces	(9)	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Tanks, voids and auxiliary machinery spaces having little or no fire risk	(10)	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Auxiliary machinery spaces, cargo spaces, special category spaces, cargo and other oil tanks and other similar spaces of moderate fire risk	(11)	A-60	A-60	A-60	A-60	A-0	A-30 A-0	A-60 A-15	A-60 A-15	A-0	A-0	A-0	A-30	A-30[b] A-0	A-30
Machinery spaces and main galleys	(12)	A-60	A-60	A-60	A-60	A-0	A-60	A-60	A-60	A-0	A-0	A-60	A-60	A-60	A-60
Store-rooms, workshops, pantries, etc.	(13)	A-60	A-60 A-15	A-30 A-0	A-15	A-0	A-15 A-0	A-30 A-0	A-60 A-15	A-0	A-0	A-0	A-30	A-0	A-30
Other spaces in which flammable liquids are stowed	(14)	A-60	A-60	A-60	A-60	A-0	A-60	A-60	A-60	A-0	A-0	A-60	A-60	A-60	A-60

See notes under Table 6d.

Table 6c Bulkheads not bounding either main vertical zones or horizontal zones; passenger ships carrying more than 36 passengers

Spaces		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Control stations	(1)	B-0[a]	A-0	A-0	A-0	A-0 B-0	A-60	A-60	A-60	A-0	A-0	A-60	A-60	A-60	A-60
Stairways	(2)		A-0[a]	A-0	A-0	A-0	A-0	A-15 A-0	A-30 A-0	A-0	A-0	A-15	A-30	A-15 A-0	A-30
Corridors	(3)			C	A-0	A-0 B-0	B-0	B-15 B-0	B-15 B-0	B-0	A-0	A-15	A-30	A-0	A-30 A-0
Lifeboat and liferaft handling and embarkation stations	(4)				—	—	A-0	A-0	A-0	A-0	A-0	A-0	A-15	A-0	A-15 A-0
Open deck space	(5)					—	A-0 B-0	A-0 B-0	A-0 B-0	A-0 B-0	A-0	A-0	A-0	A-0 B-0	A-0 B-0
Accommodation spaces of minor fire risk	(6)						B-0 C	B-15 C	B-15 C	B-0 C	A-0	A-15 A-0	A-30	A-0	A-30 A-0
Accommodation spaces of moderate fire risk	(7)							B-15 C	B-15 C	B-0 C	A-0	A-15 A-0	A-60	A-15 A-0	A-60 A-15
Accommodation spaces of greater fire risk	(8)								B-15 C	B-0 C	A-0	A-30 A-0	A-60	A-15 A-0	A-60 A-15
Sanitary and similar spaces	(9)									C	A-0	A-0	A-0	A-0	A-0
Tanks, voids and auxiliary machinery spaces having little or no fire risk	(10)										A-0[a]	A-0	A-0	A-0	A-0
Auxiliary machinery spaces, cargo spaces, cargo and other oil tanks and other similar spaces of moderate fire risk	(11)											A-0[a]	A-0	A-0	A-30[b] A-15
Machinery spaces and main galleys	(12)												A-0[a]	A-0	A-60
Store-rooms, workshops, pantries, etc.	(13)													A-0[a]	A-0
Other spaces in which flammable liquids are stowed	(14)														A-30[b] A-15

See notes under Table 6d.

Table 6d Decks not forming steps in main vertical zones nor bounding horizontal zones; passenger ships carrying more than 36 passengers

Space below↓ Space above→		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Control stations	(1)	A-30 A-0	A-30 A-0	A-15 A-0	A-0	A-0 B-0	A-0	A-15 A-0	A-30 A-0	A-0	A-0	A-0	A-60	A-0	A-60 A-15
Stairways	(2)	A-0	A-0	A-0	A-0	A-0 B-0	A-0	A-0	A-0	A-0	A-0	A-0	A-30	A-0	A-30 A-0
Corridors	(3)	A-15 A-0	A-0	A-0[a] B-0[a]	A-0	A-0 B-0	A-0 B-0	A-15 B-0	A-15 B-0	A-0 B-0	A-0	A-0	A-30	A-0	A-30 A-0
Lifeboat and liferaft handling and embarkation stations	(4)	A-0	A-0	A-0	A-0	—	A-0 B-0	A-0 B-0	A-0 B-0	A-0 B-0	A-0	A-0	A-0	A-0	A-0
Open deck spaces	(5)	A-0	A-0	A-0 B-0	A-0	—	A-0 B-0	A-0 B-0	A-0 B-0	A-0 B-0	A-0	A-0	A-0	A-0 B-0	A-0
Accommodation spaces of minor fire risk	(6)	A-60	A-15 A-0	A-0	A-0	A-0 B-0	A-0 B-0	A-0 B-0	A-0 B-0	A-0 B-0	A-0	A-0	A-15 A-0	A-0	A-15 A-0
Accommodation spaces of moderate fire risk	(7)	A-60	A-30 A-0	A-15 A-0	A-15 A-0	A-0 B-0	A-0 B-0	A-15 B-0	A-30 B-0	A-0 B-0	A-0	A-15 A-0	A-30 A-0	A-0	A-30 A-0
Accommodation spaces of greater fire risk	(8)	A-60	A-60 A-15	A-60 A-0	A-30 A-0	A-0 B-0	A-15 B-0	A-30 B-0	A-60 B-0	A-0 B-0	A-0	A-30 A-0	A-30 A-0	A-0	A-30 A-0
Sanitary spaces and similar spaces	(9)	A-0	A-0	A-0 B-0	A-0	A-0 B-0	A-0 B-0	A-0 B-0	A-0 B-0	A-0 B-0	A-0	A-0	A-0	A-0	A-0
Tanks, voids and auxiliary machinery spaces having little or no fire risk	(10)	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0[a]	A-0	A-0	A-0	A-0
Auxiliary machinery spaces, cargo spaces, cargo and other oil tanks and other similar spaces of moderate fire risk	(11)	A-60	A-60 A-15	A-60 A-15	A-30 A-0	A-0	A-0	A-15 A-0	A-30 A-0	A-0	A-0	A-0[a]	A-0	A-0	A-30[b] A-15
Machinery spaces and main galleys	(12)	A-60	A-60	A-60	A-60	A-0	A-60	A-60	A-60	A-0	A-0	A-30	A-30[a]	A-0	A-60
Store-rooms, workshops, pantries, etc.	(13)	A-60	A-30 A-0	A-15 A-0	A-15 A-0	A-0 B-0	A-15 A-0	A-30 A-0	A-30 A-0	A-0 B-0	A-0	A-0	A-0	A-0	A-15[b] A-0
Other spaces in which flammable liquids are stowed	(14)	A-60	A-60 A-30	A-60 A-30	A-60	A-0	A-30 A-0	A-60 A-15	A-60 A-15	A-0	A-0	A-30[b] A-0	A-30[b] A-0	A-0	A-30[b] A-0

NOTES:

a. Where adjacent spaces are in the same numerical category and superscript [a] appears, a bulkhead or deck between such spaces need not be fitted. For example, in category (12) a bulkhead need not be required between a galley and its annexed pantries provided the pantry bulkheads and decks maintain the integrity of the galley boundaries. A bulkhead is, however, required between a galley and a machinery space even though both spaces are in category (12).

b. Where superscript [b] appears the lesser insulation value may be permitted only if at least one of the adjoining spaces is protected by an automatic sprinkler system complying with the provisions of Regulation 12 of the Amendments.

Tables 7a and 7b Classification of spaces according to fire risk

The number in parentheses preceding each category refers to the applicable column or row number in the Tables.

(1) *Control stations*

Spaces containing emergency sources of power and lighting.

Wheelhouse and chartroom.

Spaces containing the ship's radio equipment.

Fire-extinguishing rooms, fire control stations and fire-recording stations.

Control room for propulsion machinery when located outside the machinery space.

Spaces containing centralized fire alarm equipment.

(2) *Corridors*

Passenger and crew corridors and lobbies.

(3) *Accommodation spaces*

Spaces as defined in Glossary, excluding corridors.

(4) *Stairways*

Interior stairways, lifts and escalators (other than those wholly contained within the machinery spaces) and enclosures thereto.

In this connection, a stairway which is enclosed only at one level shall be regarded as part of the space from which it is not separated by a fire door.

(5) *Service spaces (low risk)*

Lockers and store-rooms having an area of less than 2 m^2, drying rooms and laundries.

(6) *Machinery spaces of Category A*

Spaces as defined in Glossary.

(7) *Other machinery spaces*

Spaces as defined in Glossary excluding machinery spaces of category A.

(8) *Cargo spaces*

All spaces used for cargo (including cargo oil tanks) and trunkways and hatchways to such spaces other than special category spaces.

(9) *Service spaces (high risk)*

Galleys, pantries containing cooking appliances, paint and lamp rooms, lockers and store-rooms having an area of 2 m^2 or more, workshops other than those forming part of the machinery spaces.

(10) *Open decks*

Open deck spaces and enclosed promenades having no fire risk. Air spaces (the space outside superstructures and deckhouses).

(11) *Ro/Ro cargo spaces*

Spaces as defined in Glossary.

Table 7a Fire integrity of bulkheads separating adjacent spaces; passenger ships carrying up to 36 passengers

Spaces		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Control stations	(1)	A-0[c]	A-0	A-60	A-0	A-15	A-60	A-15	A-60	A-60	*	A-60
Corridors	(2)		C[e]	B-0[e]	0[a] B-0[e]	B-0[e]	A-60	A-0	A-0	A-15 A-0[d]	*	A-15
Accommodation spaces	(3)			C[e]	A-0[a] B-0[e]	B-0[e]	A-60	A-0	A-0	A-15 A-0[d]	*	A-30 A-0[d]
Stairways	(4)				A-0[a] B-0[e]	A-0[a] B-0[e]	A-60	A-0	A-0	A-15 A-0[d]	* *	A-15
Service spaces (low risk)	(5)					C[e]	A-60	A-0	A-0	A-0	*	A-0
Machinery spaces of Category A	(6)						*	A-0	A-0	A-60	*	A-60
Other machinery spaces	(7)							A-0[b]	A-0	A-0	*	A-0
Cargo spaces	(8)								*	A-0	*	A-0
Service spaces (high risk)	(9)									A-0[b]	*	A-30
Open decks	(10)										—	A-0
Special Category spaces	(11)											A-0

See notes under Table 7b.

Table 7b Fire integrity of decks separating adjacent spaces; passenger ships carrying up to 36 passengers

Space below↓ Space above→		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Control stations	(1)	A-0	A-0	A-0	A-0	A-0	A-60	A-0	A-0	A-0	*	A-30
Corridors	(2)	A-0	*	*	A-0	*	A-60	A-0	A-0	A-0	*	A-0
Accommodation spaces	(3)	A-60	A-0	*	A-0	*	A-60	A-0	A-0	A-0	*	A-30 A-0[d]
Stairways	(4)	A-0	A-0	A-0	*	A-0	A-60	A-0	A-0	A-0	*	A-0
Service spaces (low risk)	(5)	A-15	A-0	A-0	A-0	*	A-60	A-0	A-0	A-0	*	A-0
Machinery spaces of Category A	(6)	A-60	A-60	A-60	A-60	A-60	*	A-60[f]	A-30	A-60	*	A-60
Other machinery spaces	(7)	A-15	A-0	A-0	A-0	A-0	A-0	*	A-0	A-0	*	A-0
Cargo spaces	(8)	A-60	A-0	A-0	A-0	A-0	A-0	A-0	*	A-0	*	A-0
Service spaces (high risk)	(9)	A-60	A-30 A-0[d]	A-30 A-0[d]	A-30 A-0[d]	A-0	A-60	A-0	A-0	A-0	*	A-30
Open decks	(10)	*	*	*	*	*	*	*	*	*	—	A-0
Special category spaces	(11)	A-60	A-15	A-30 A-0[d]	A-15	A-0	A-30	A-0	A-0	A-30	A-0	A-0

NOTES:

a For clarification as to which applies see Regulations 25 and 29 of the Amendments

b Where spaces are of the same numerical category and superscript b appears, a bulkhead or deck of the ratings shown in the Tables is only required when the adjacent spaces are for a different purpose, e.g. in Category (9). A galley next to a galley does not require a bulkhead but a galley next to a paint room requires an "A-0" bulkhead.

c Bulkheads separating the wheelhouse and chartroom from each other may be "B-0" rating.

d See 2.3 and 2.4 of Regulation 27.

e For the application of Regulation 24.1.2, "B-0" and "C", where appearing in Table 7a, shall be read as "A-0".

f Fire insulation need not be fitted if the machinery space of Category (7) has little or no fire risk.

* Where an asterisk appears in the Tables, the division is required to be of steel or other equivalent material but is not required to be of "A" class standard.
For the application of Regulation 24.1.2 an asterisk, where appearing in Table 7b, except for Categories (8) and (10) shall be read as "A-0".

4.1.3 Doors

All doors and their frames and the means of securing them when closed are required to provide a resistance to fire, as far as practicable, equivalent to that of the bulkhead in which they are situated. Doors may be single or double leaf and be either hinged or sliding types.

A-0 class doors are usually of hollow box construction stiffened internally and when packed with insulating material will give the required fire rating, namely either A-15, A-30 or A-60. The requirement for internal stiffening is dependent on size and also the gauge of the sheet steel on the external surfaces. However, any internal stiffening provided should not have a direct fastening to both faces of the door since this will give rise to heat transmission from the fire exposed face to the other side of the door. The nature of the construction of fire doors does not lend itself to great strength nor is the location of some fire doors of much assistance to the regular flow of traffic to such areas as the entrances to dining rooms etc., where the doors could be damaged by constantly being opened and closed. In cases like this it is normal for hold-open devices, such as magnetic retainers, to be fitted. Magnetic retainers depend on a flow of electric current for their magnetism, thus they can be linked either to the fire detection system or to a push button control at the bridge and will automatically be released in the event of fire to close under the action of a spring or pneumatic/hydraulic cylinder. The hold open device is not mandatory but, if fitted, it must be of the automatic fail-safe type.

Some flag authorities require hinged doors to be provided with three strong hinges and a three-point securing mechanism operated by a handle which controls bolts on the three free sides. However, some manufacturers have carried out successful fire tests on doors with a single latch securing mechanism and these may be used, but it should always be checked that a single latch mechanism is also acceptable to the flag administration since not all have agreed their use despite successful fire testing. Sliding doors are suspended from a rail by rollers and the bottom edge is restrained from lateral movement. All doors in main vertical or horizontal zones or to stairway enclosures should be capable of being opened from both sides by one person and be self-closing against a $3\frac{1}{2}$ degree adverse list. This latter requirement can cause difficulties, since it is difficult to design a mechanism whereby a door will close efficiently against such a list and yet avoid slamming when there is a list which assists closure. Slamming has been known to cause serious bodily injury. The doors should be arranged to close rapidly under the action of a powerful spring, but the force of the final closure is reduced by a pneumatic damper or other suitable device. If hold-open devices are fitted to these doors, then they must be capable of remote release from a central control position.

When double-leaf doors are fitted arrangements have to be provided to ensure that the doors close in the sequence necessary to effect the correct closure. The effectiveness of all doors is required to be proved by a standard fire test and any door which is fitted should be constructed under survey in accordance with approved plans and covered by a certificate of test by a recognised authority. Sliding watertight doors of traditional construction are accepted without insulation as doors in fire bulkheads.

When a ship is being examined the surveyors should ensure that each door is a type which has been approved for the position and that, when required, it will close automatically from the fully open position and also when it has been opened just sufficiently for an average person to pass through. Surveyors should verify that it can be opened readily from both sides by one person and test the local and remote release mechanism if the door is normally held open. Hooks must not be fitted for this purpose.

4.1.4 Insulation of "A" and "B" Class Divisions

All insulating materials used for achieving the limitation of temperature rise on fire divisions should be non-combustible. The use of asbestos in fire divisions has almost completely died out for the obvious health reasons and the materials in most common use today are mineral wools, ceramic fibres, vermiculite/cement mixtures and calcium silicate board materials. Figures 12(a) to 12(k) show some commonly found arrangements. Sprayed-on coatings are applied by machine directly to the surface of the division which will probably have been prepared by fixing a wire mesh to clips welded to the steel which gives a secure "key" for the material to adhere to the division. With this type of coating care must be taken to ensure that the required thickness is achieved uniformly over the division. Mineral wool or ceramic fibre slabs or mattresses can be readily cut to shape and forced over steel clips attached to the division. Wire netting is then spread over the whole surface, washers placed over the clips and the clips bent over to firmly secure the matrix to the division. Rigid board materials can either be attached directly to the division or erected with a predetermined air gap and attached to the division or adjacent structure. Rigid board materials have the advantage of being able to be faced with decorative laminates thus providing both a fire division and an attractive finished surface.

Whatever form of insulation is used, provision must be made to prevent the transfer of the fire from one side of the division to the other by conduction along metallic boundaries such as decks, shell and bulkheads, or where the division is pierced by pipes, girders, ducts, etc. To achieve this all such surfaces are insulated for a distance of at least 450 mm, measured from the division.

Since every type of insulation is approved in association with its method of attachment, in all cases the method of erection or attachment of the insulation must be in accordance with those features of the specimen during the official test and as verified by the certificate of approval—a fact which, though obvious, seems often to be overlooked by many.

4.1.5 Deck Coverings

Deck coverings may constitute a fire hazard to an extent which depends on their flame spread characteristic and on whether the material will burn readily when heated from below through a steel plate.

Primary deck coverings should be of approved materials which will not readily ignite.

4.1.6 Protection of Stairways

Stairways must be enclosed for two reasons, one is to facilitate the escape of personnel from all levels of the accommodation to the embarkation deck and the second is to prevent the spread of fire from one deck level to the next.

All stairways should be of steel frame construction, except that aluminium may be used, provided it is adequately protected by insulation. They should be enclosed by "A" Class divisions with positive means of closure at all levels; at least up to a level where there is direct access to the open deck. Where a stairway serves only two decks it need only be enclosed at one level. The requirement generally is that main stairway enclosures at main fire zones should be "A-60" Class, but this may be reduced if the fire risk on the opposite side is not great as seen in Tables 6 and 7.

When a ventilation duct traverses a stairway enclosure and does not serve the stairway, it must be constructed to "A-60" standards within the enclosure, but the dampers which would normally be required at the penetrations of the "A" Class bulkheads need not be fitted, *see* Tables 6 and 7.

4.1.7 Protection of Lifts and Trunks

Although in any emergency, for obvious reasons passenger lifts should not be used, lift trunks, both for the carriage of passengers and goods, require protection, since they could provide a route for the fire to travel from one level to another. If unprotected they could also produce a "chimney effect" which would intensify the fire.

All lift trunks are, therefore, constructed of steel or other equivalent material and are usually insulated to "A-60" standard. The doors are to be self closing and of equivalent fire resistance to the trunk as shown in Tables 6 and 7.

4.1.8 Miscellaneous Items

To prevent the passage of fire above ceilings and behind panelling or linings, all concealed surfaces are required to have low flame spread characteristics and draught stops should be fitted about 14 metres apart.

Small holes about 25 mm in diameter, are often bored in ceilings and panelling or linings so that smoke from hidden fires may escape and be seen. These holes are usually fitted with grilles to prevent the passage of vermin.

With the exception of cargo spaces, baggage rooms or refrigerated compartments of service spaces, the construction materials used for linings, grounds, ceilings and insulation must be non-combustible. Materials used for vapour barriers, adhesives and pipework insulation for cold service systems may be combustible but should be kept to a minimum and have low surface spread of flame characteristics.

Where decorative combustible surfacings are used on either exposed or concealed surfaces of corridors, stairway enclosures and wall and ceiling linings in all accommodation spaces and control stations, these should not exceed the equivalent of a 2.5 mm veneer on the exposed combined surface area of the walls and ceilings and have a calorific value not exceeding 45 MJ/m^2 for the actual thickness used.

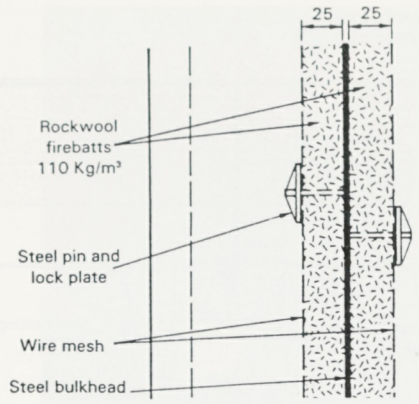
For "rooms containing furniture and furnishings of restricted fire risk" the requirements are defined in the glossary given in Section 5.

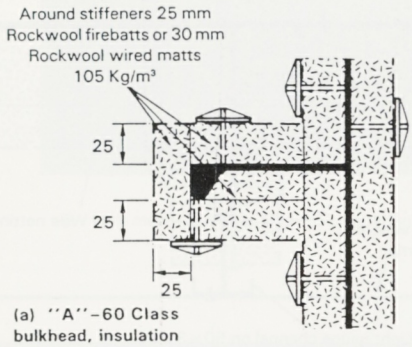
Pipes conveying oil or other combustible liquids must be made of materials which will not ignite or readily deform due to heat; similar care must be exercised in respect of scupper pipes and overboard discharges. All waste-paper bins and cigarette receptacles must be made of non-combustible materials.

4.1.9 Means of Escape

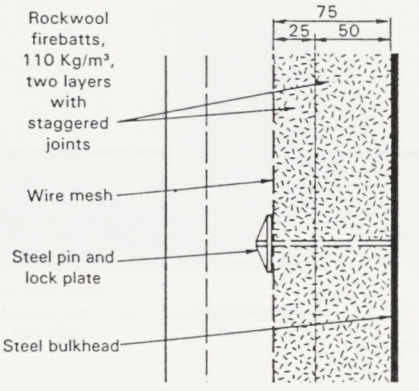
The provision of adequate means of escape is of extreme importance. They must be as direct as possible, easy to find, of adequate width, bearing in mind the number of persons who may have to use them in an emergency, and be of such construction that they will form a continuous fire shelter from the lowest level of accommodation to the embarkation deck.

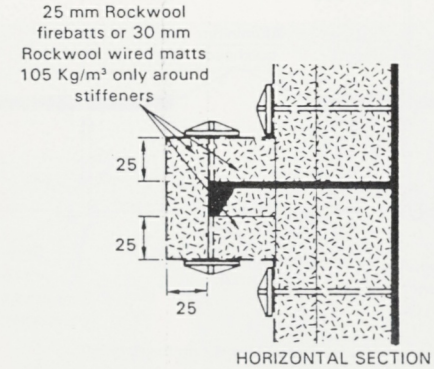
In passenger and crew spaces below the bulkhead deck, two means of escape are required from each main vertical fire zone,



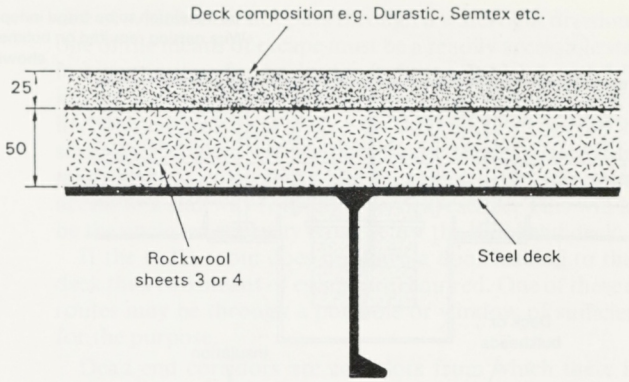


(a) "A"-60 Class bulkhead, insulation both sides

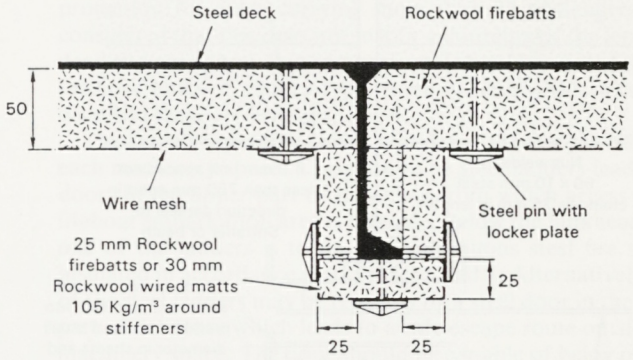




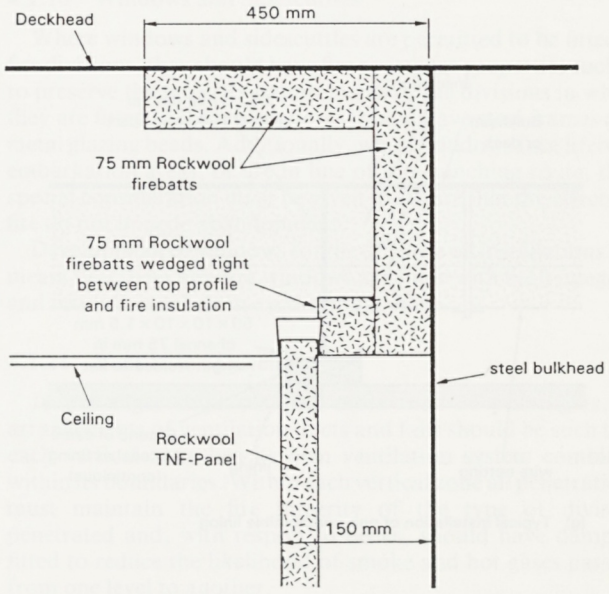
(b) "A"-60 Class bulkhead, insulation one side



(c) "A"-60 Class deck, insulation on top



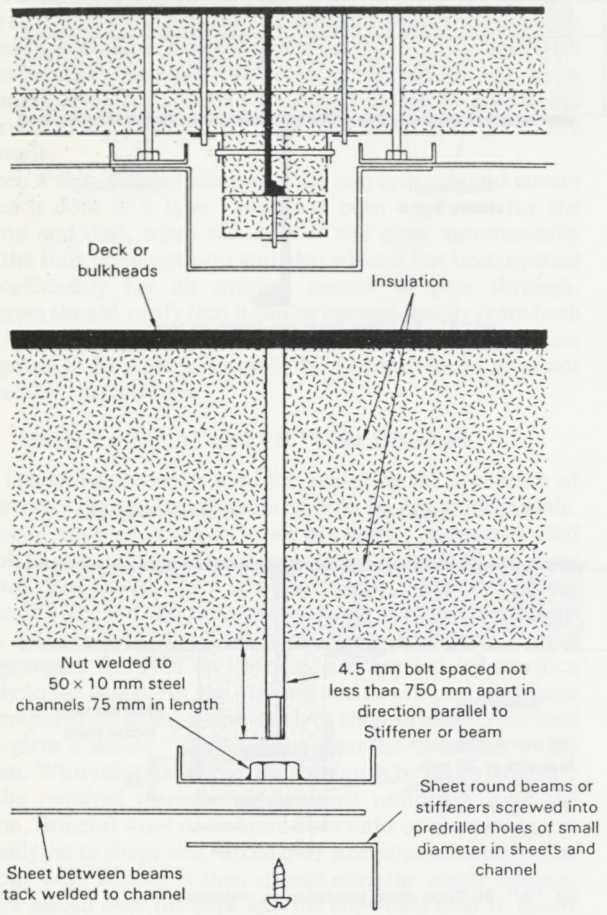
(d) "A"-60 Class deck, insulation on underside



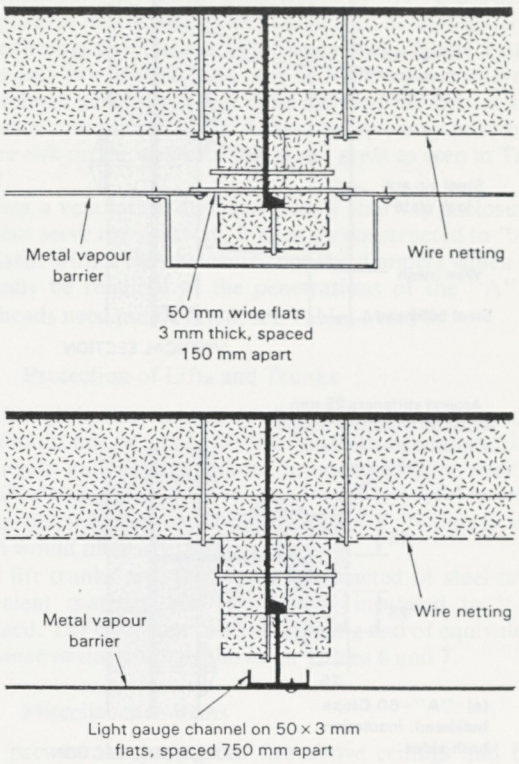
(e) "A"-60 Class bulkhead including fire insulation of space between top of lining and bulkhead

Fig. 12(a)-(e) Typical insulation details

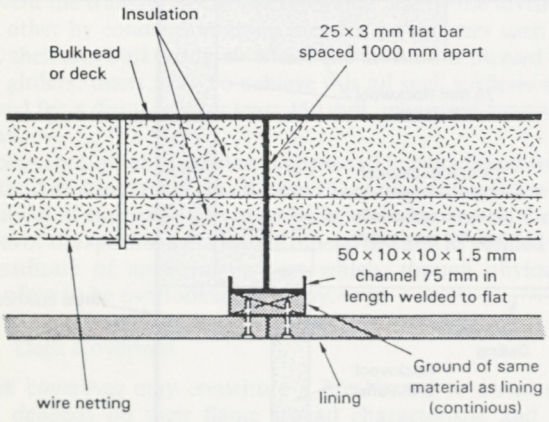
Fire insulation to be fitted independently of vapour barriers
Wire netting required on bulkheads and deck insulation as shown



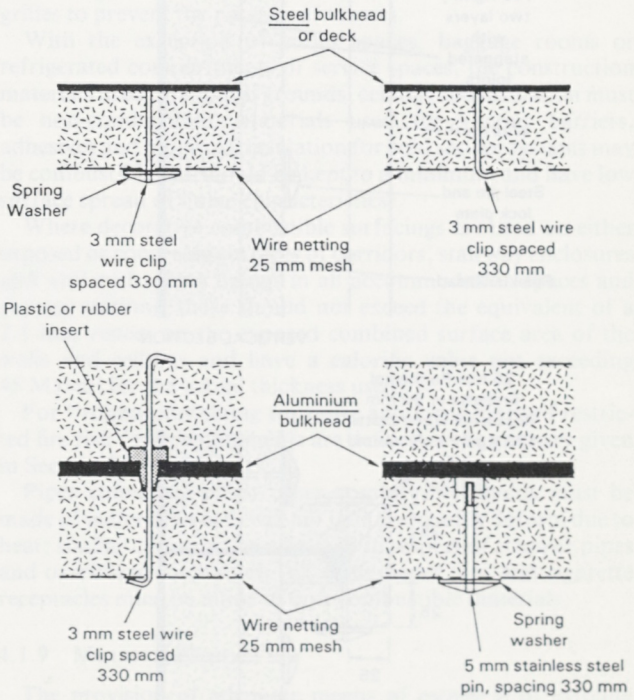
(f) Typical insulation details with metal vapour barrier



(h) Typical insulation details with metal vapour barrier

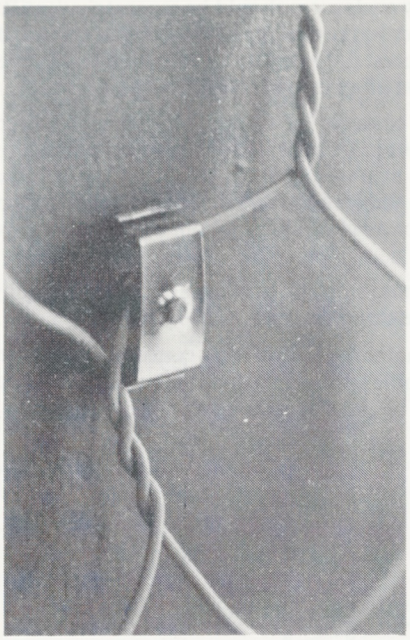


(g) Typical installation of non-combustible lining

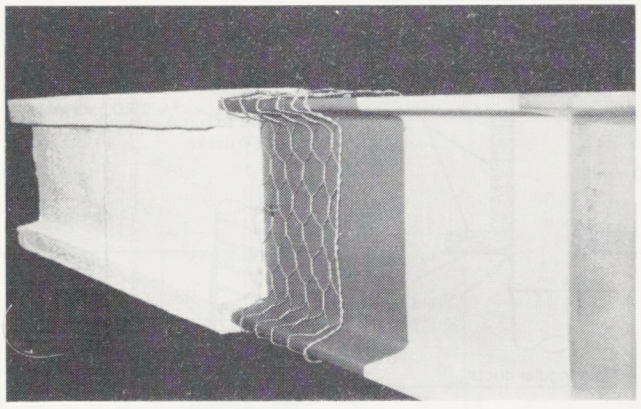


(i) Typical insulation fixing details

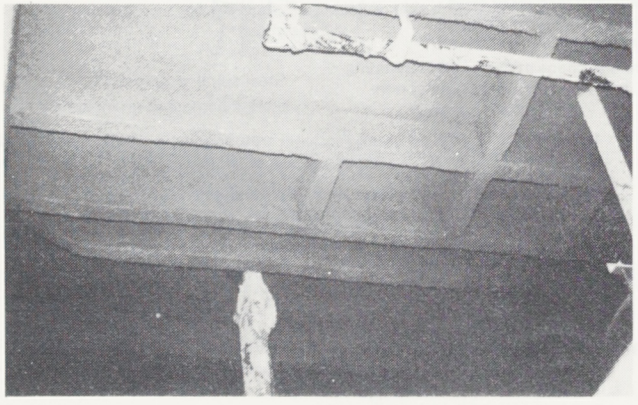
Fig. 12(f)–(i) Typical insulation details



(j) Wire mesh "key" for sprayed-on coatings



(k) Sequence of construction



(l) Finished coating

Fig. 12(j)–(l) Typical insulation details

one of which must not pass through a watertight division. Also one of the means of escape must be a readily accessible stairway in a continuous fire enclosure (refer to Tables 6 and 7 for fire integrity ratings) from the lowest level necessary up to the lifeboat embarkation deck, or the top level served by the stairway if higher. Of the two escape routes required in each main vertical zone above the bulkhead deck, one must give access to a stairway forming a vertical escape. This will usually be the enclosed stairway from below the bulkhead deck.

If the radio room does not have a door leading to the open deck then two means of escape are required. One of these escape routes may be through a porthole or window of sufficient size for the purpose.

Dead-end corridors are corridors from which there is only one exit. If that escape is blocked, for example by fire, persons accommodated on the corridor would be trapped. Consequently dead-end corridors are restricted to 13 metres in length for ships carrying more than 36 passengers but not exceeding 7 metres in length for ships carrying no more than 36 passengers, which is the same as for cargo ships. It could be argued that whilst there is a higher standard of structural fire protection for ships carrying more than 36 passengers, it is considered that this does not justify a doubling of the length of dead end corridors. As a comparison it should be noted that on offshore units of similar type, floating hotels, the maximum dead end length is 5 metres.

Two widely separated means of escape are to be provided for each machinery space. These are to be steel ladders leading to doors in the upper part of the space from which access to the lifeboat embarkation area is possible. Below the bulkhead deck one of the ladders is to be in a continuous steel fire shelter insulated in accordance with Tables 6 and 7. Alternatively, one of the steel ladders may be replaced by a steel door in the lower part of the space which leads to a safe escape route outside the machinery space. The door should be capable of being opened from either side and must be as widely separated as possible from the steel ladder providing escape inside the space.

Aluminium floorplates or gratings are not permitted by the Society in machinery spaces and similar high fire risk areas. Lifts should not be considered as forming a means of escape.

4.1.10 Windows and Sidescuttles

Where windows and sidescuttles are permitted to be fitted in fire divisions, they should have fire resistance properties such as to preserve the integrity requirements of the divisions in which they are fitted. All such windows should have steel frames and metal glazing beads. Additionally, where windows face lifeboat embarkation areas, or are in line of the launching route, then special consideration must be given to ensure that the effects of fire do not impede abandonment.

Development of windows for the offshore oil installations has meant that there now are windows available with both integrity and insulation values in excess of one hour.

4.1.11 Ventilation Systems

In passenger ships carrying more than 36 passengers the arrangements of ventilation ducts and fans should be such that each vertical zone has its own ventilation system combined within its boundaries. Within each vertical zone all penetrations must maintain the fire integrity of the type of division penetrated and, with respect to decks, should have dampers fitted to reduce the likelihood of smoke and hot gases passing from one level to another.

Except for cargo spaces, the materials used for the construction of ventilation ducts should be as follows:

(i) Ducts not less than 0.075 m^2 in sectional area and all vertical ducts serving more than a single "tweendeck" space are to be constructed of steel or other equivalent material.

(ii) Ducts less than 0.075 m² in sectional area, except vertical ducts, are to be constructed of non-combustible materials. Where such ducts penetrate "A" or "B" class divisions due regard shall be given to ensuring the fire integrity of the division.

(iii) Short lengths of duct, not in general exceeding 0.02 m² in sectional area nor 2 metres in length, need not be non-combustible provided that all of the following conditions are met:

(a) The duct is constructed of a material of low fire risk.

(b) The duct is used only at the terminal end of the ventilation system.

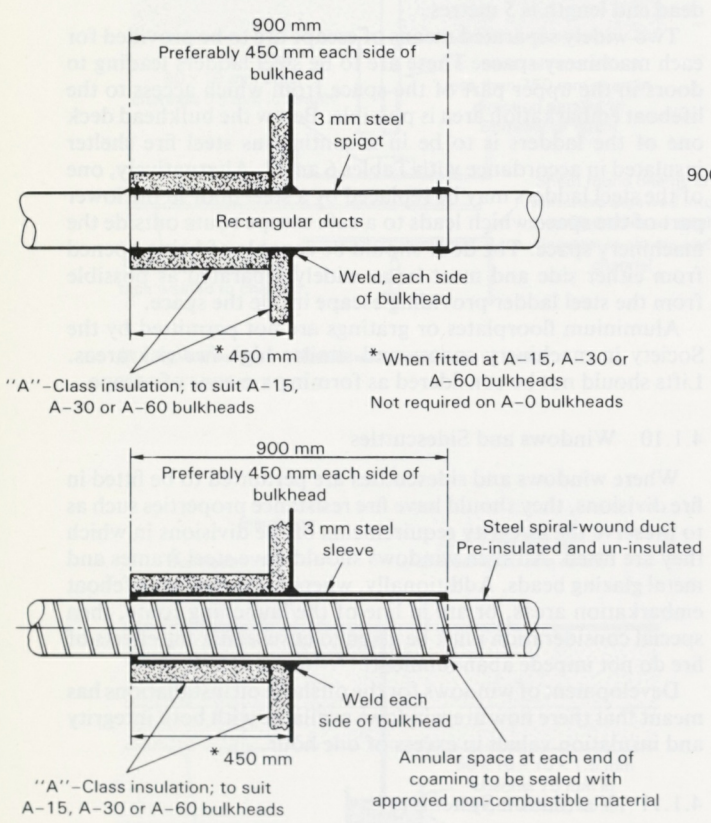
(c) The duct is not located closer than 600 mm, measured along its length, to a penetration of an "A" or "B" class division, including continuous "B" class ceilings.

Stairway enclosures should be separately ventilated from all other spaces to prevent the obvious rapid spread of fire should the enclosures' fire integrity be breached and to prevent smoke obscuration of an escape route.

Remote controls for stopping the fans of power ventilation systems should be provided. Two separate positions are to be provided, as far apart as possible, for all spaces except machinery and cargo spaces. Two separate control positions are required for machinery spaces but one of them must be outside the space.

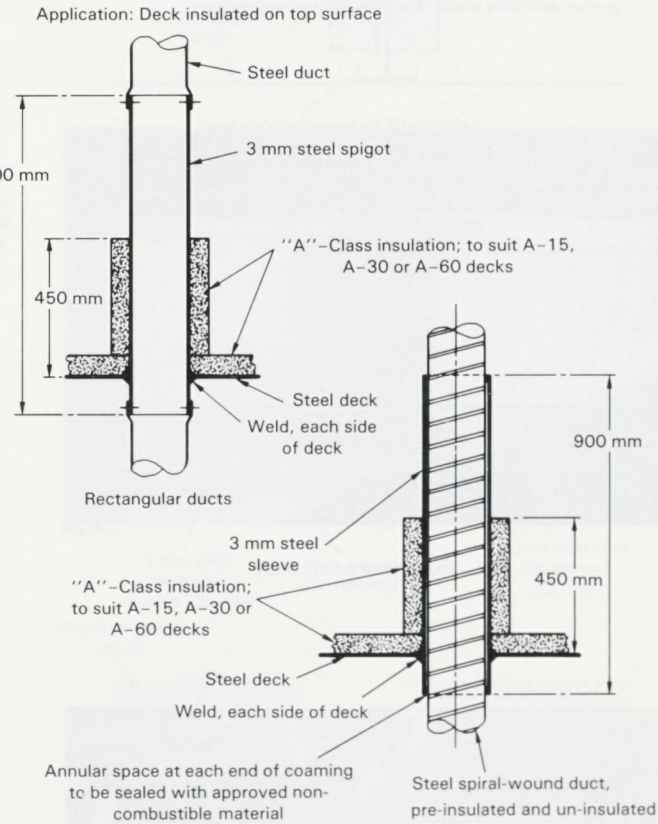
The remote stop for cargo spaces fans need only be located outside the cargo spaces.

The remaining requirements concerning ventilation systems are applicable to all ships and the typical provisions are better illustrated by the diagrams given in Figure 13.



Ducts of over 0.075 m² cross-sectional area, require in addition, approved fire dampers, see detail (e).

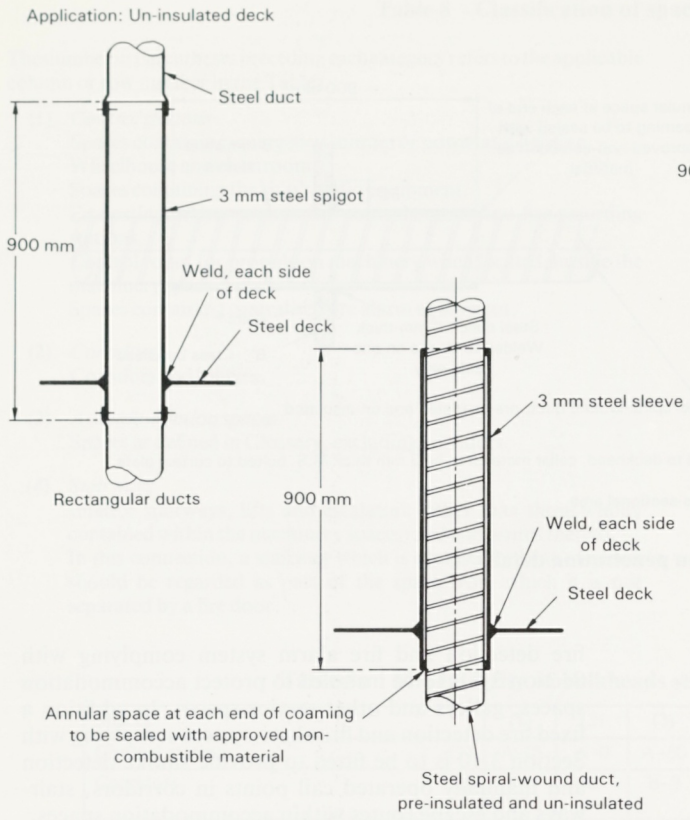
(a) Penetration of "A"-Class bulkheads for steel ducts exceeding 0.002 m² and up to 0.0075 m² cross-sectional area.



Ducts of over 0.075 m² cross-sectional area, require in addition, approved fire dampers, see detail (e).

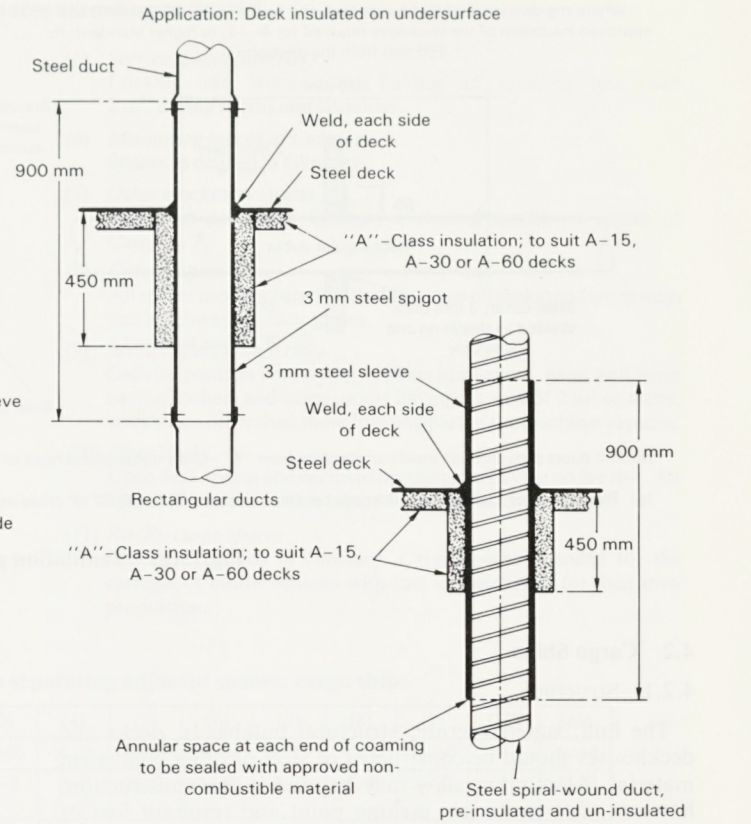
(b) Penetration of "A"-Class decks for steel ducts exceeding 0.02 m² and up to 0.075 m² cross-sectional area.

Fig. 13(a) and (b) Ventilation penetration details



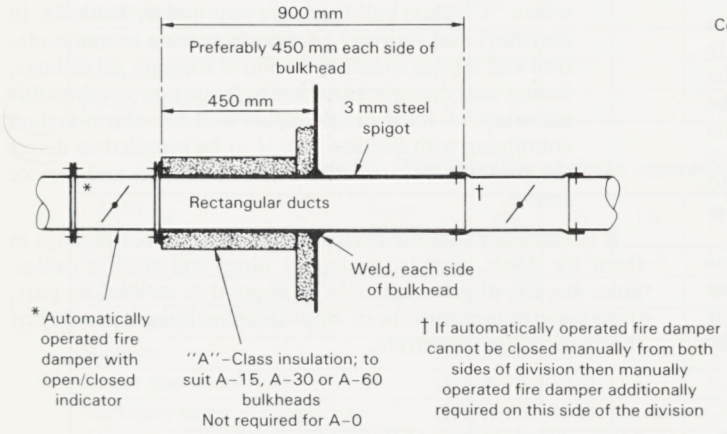
Ducts of over 0.075 m² cross-sectional area, require in addition, approved fire dampers, see detail (e).

(c) Penetration of "A"-Class decks for steel ducts exceeding 0.02 m² and up to 0.075 m² cross-sectional area.



Ducts of over 0.075 m² cross-sectional area, require in addition, approved fire dampers, see detail (e).

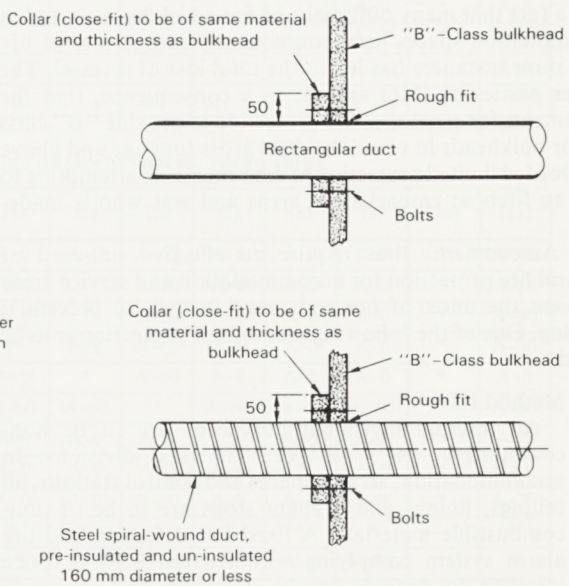
(d) Penetration of "A"-Class decks for steel ducts exceeding 0.02 m² and up to 0.075 m² cross-sectional area.



Notes: 1. Provided fire damper casing complies with the thickness requirements of Regulation 16.3 then the casing may form part of the 900 mm long spigot

2. *See* Regulations 16.3 and 16.4 for the special provisions required where ventilation ducts serving accomodation, service spaces or control stations necessarily pass through machinery spaces of category A, galleys, car decks, ro-ro spaces or special category spaces, or vice versa

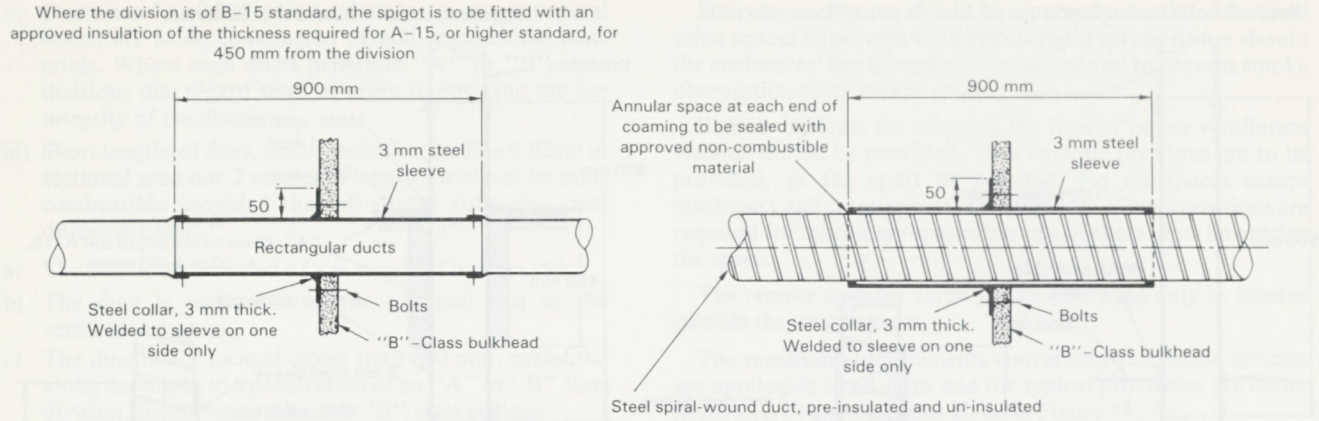
(e) Penetration of "A"-Class bulkhead for steel ducts exceeding 0.075 m² cross-sectional area.



Note: If ducts pass through steel curtain plate from "B"-Class material bulkhead to deckhead, collar material may be 1.00 mm thick galvanized steel, bolted to curtain plate. Similar arrangements may also be used for steel ducts of 0.02 m² cross-sectional area, or less, passing through "A"-Class bulkheads

(f) Penetration of "B"-Class bulkheads for steel ducts of 0.02 m² cross-sectional area, or less

Fig. 13(c)-(f) Ventilation penetration details



Note: If ducts pass through steel curtain plate from "B"–Class material bulkhead to deckhead, collar material to be 3 mm thick M.S. bolted to curtain plate

(g) Penetration of "B"–Class bulkheads for steel ducts exceeding 0.02 m² cross-sectional area

Fig.13(g) Ventilation penetration details

4.2 Cargo Ships

4.2.1 Structure

The hull, superstructure, structural bulkheads, decks and deckhouses should be constructed of steel or other equivalent material. Aluminium alloy may be used in the construction, however, due to its low melting point and resultant loss of structural integrity, its use is limited to that given in 4.1.1.

The crowns and casings of machinery spaces of Category A should be of steel construction adequately insulated and any openings should be suitably arranged and protected to prevent the spread of fire.

4.2.2 Structural Fire Protection

It is a fact that many outbreaks of fire which have started in accommodation spaces have consequently caused loss of life and in some instances has led to the total loss of a vessel. The member parties of IMO agreed, as a consequence, that the requirements for structural fire protection to provide "B" class corridor bulkheads in vessels of 4000 gross tonnage and above only afforded limited protection to crew members attempting to escape to lifeboat embarkation areas and was wholly inadequate.

The Amendments thus require an effective standard of structural fire protection for accommodation and service areas to prevent the onset of fire and, once started, to prevent it spreading. One of the following methods of protection is to be selected:

(a) Method IC

All internal divisional bulkheads are to be non-combustible "A", "B" or "C" class divisions. In accommodation, service spaces and control stations, all ceilings, linings and draught stops are to be of non-combustible materials. A fixed fire detection and fire alarm system complying with Section 3.10 is to be installed to provide smoke detection and manually operated call points in all corridors, stairways and escape routes within accommodation spaces.

(b) Method IIC

Bulkheads not required by Table 8a to be "A", "B" or "C" class divisions need have no restriction in their construction. In corridors and stairway enclosures serving accommodation and service spaces and control stations, all ceilings, linings and draught stops are to be of non-combustible materials. An automatic sprinkler, fire detection and fire alarm system complying with Section 3.5 is to be installed to protect accommodation spaces, galleys and other service spaces. In addition a fixed fire detection and fire alarm system complying with Section 3.10 is to be fitted to provide smoke detection and manually operated call points in corridors, stairways and escape routes within accommodation spaces.

(c) Method IIIC

Bulkheads not required by Table 8a to be "A", "B" or "C" class divisions need have no restriction in their construction except that the area of any accommodation space or spaces bounded by a continuous "A" or "B" class division should in no case exceed 50 m² except where "C" class bulkheads are required by Table 8a. In corridors and stairway enclosures serving accommodation and service spaces and control stations, all ceilings, linings and draught stops are to be of non-combustible materials. A fixed fire detection and fire alarm system complying with Section 3.10 is to be installed to detect the presence of fire in all accommodation and service spaces.

It is necessary that fire divisions require to have openings in them for doors, ventilation trunks pipes and electric cables. Since any fire division can only be as good as its weakest part, these penetrations must be of equivalent fire integrity to that of the division they penetrate.

4.2.3 Fire Integrity of Bulkheads and Decks

The minimum fire integrity of bulkheads and decks should be as prescribed in Tables 8a and 8b.

4.2.4 Doors

All doors and their frames and the means of securing them when closed are required to provide a resistance to fire, as far as practicable, equivalent to that of the bulkhead in which they are situated. Where fitted in engine room casing bulkheads, they should be self-closing without any hold-back facility.

4.2.5 Insulation of "A" and "B" Class Divisions

Reference should be made to 4.1.4 and to Figures 12a to 12k.

Table 8 Classification of spaces according to fire risk

The number in parentheses preceding each category refers to the applicable column or row number in the Tables.

(1) *Control stations*
Spaces containing emergency sources of power and lighting.
Wheelhouse and chartroom.
Spaces containing the ship's radio equipment.
Fire-extinguishing rooms, fire control rooms and fire-recording stations.
Control room for propulsion machinery when located outside the machinery space.
Spaces containing centralised fire alarm equipment.

(2) *Corridors*
Corridors and lobbies.

(3) *Accommodation spaces*
Spaces as defined in Glossary, excluding corridors.

(4) *Stairways*
Interior stairways, lifts and escalators (other than those wholly contained within the machinery spaces) and enclosures thereto.
In this connection, a stairway which is enclosed only at one level should be regarded as part of the space from which it is not separated by a fire door.

(5) *Service spaces (low risk)*
Lockers and store-rooms having an area of less than 2 m^2, drying rooms and laundries.

(6) *Machinery spaces of Category A*
Spaces as defined in Glossary.

(7) *Other machinery spaces*
Spaces as defined in Glossary excluding machinery spaces of Category A.

(8) *Cargo spaces*
All spaces used for cargo (including cargo oil tanks) and trunkways and hatchways to such spaces.

(9) *Service spaces (high risk)*
Galleys, pantries containing cooking appliances, paint and lamp rooms, lockers and store-rooms having an area of 2 m^2 or more, workshops other than those forming part of the machinery spaces.

(10) *Open decks*
Open deck spaces and enclosed promenades having no fire risk. Air spaces (the space outside superstructures and deckhouses).

(11) *Ro/Ro cargo spaces*
Spaces as defined in Glossary. Cargo spaces intended for the carriage of motor vehicles with fuel in their tanks for their own propulsion.

Table 8a Fire integrity of bulkheads separating adjacent spaces; cargo ships

Spaces		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Control stations	(1)	A-0[g]	A-0	A-60	A-0	A-15	A-60	A-15	A-60	A-60	*	A-60
Corridors	(2)		C	B-0	B-0 A-0[c]	B-0	A-60	A-0	A-0	A-0	*	A-30
Accommodation spaces	(3)			C[a,b]	B-0 A-0[c]	B-0	A-60	A-0	A-0	A-0	*	A-30
Stairways	(4)				B-0 A-0[c]	B-0 A-0[c]	A-60	A-0	A-0	A-0	* *	A-30
Service spaces (low risk)	(5)					C	A-60	A-0	A-0	A-0	*	A-0
Machinery spaces of Category A	(6)						*	A-0	A-0[g]	A-60	*	A-60[f]
Other machinery spaces	(7)							A-0[d]	A-0	A-0	*	A-0
Cargo spaces	(8)								*	A-0	*	A-0
Service spaces (high risk)	(9)									A-0[d]	*	A-30
Open decks	(10)										—	A-0
Ro-Ro cargo spaces	(11)											*[h]

Table 8b Fire integrity of decks separating adjacent spaces; cargo ships

Space below ↓ Space above →		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Control stations	(1)	A-0	A-0	A-0	A-0	A-0	A-60	A-0	A-0	A-0	*	A-60
Corridors	(2)	A-0	*	*	A-0	*	A-60	A-0	A-0	A-0	*	A-30
Accommodation spaces	(3)	A-60	A-0	*	A-0	*	A-60	A-0	A-0	A-0	*	A-30
Stairways	(4)	A-0	A-0	A-0	*	A-0	A-60	A-0	A-0	A-0	*	A-30
Service spaces (low risk)	(5)	A-15	A-0	A-0	A-0	*	A-60	A-0	A-0	A-0	*	A-0
Machinery spaces of Category A	(6)	A-60	A-60	A-60	A-60	A-60	*	A-60[i]	A-30	A-60	*	A-60
Other machinery spaces	(7)	A-15	A-0	A-0	A-0	A-0	A-0	*	A-0	A-0	*	A-0
Cargo spaces	(8)	A-60	A-0	A-0	A-0	A-0	A-0	A-0	*	A-0	*	A-0
Service spaces (high risk)	(9)	A-60	A-0	A-0	A-0	A-0	A-60	A-0	A-0	A-0[d]	*	A-30
Open decks	(10)	*	*	*	*	*	*	*	*	*	—	*
Ro-Ro cargo spaces	(11)	A-60	A-30	A-30	A-30	A-0	A-60	A-0	A-0	A-30	*	*[h]

NOTES:

a No special requirements are imposed upon bulkheads in methods IIC and IIIC fire protection.

b In case of method IIIC "B" class bulkheads of "B-0" rating shall be provided between spaces or groups of spaces of 50 m^2 and over in area.

c For clarification as to which applies, *see* Regulations 43 and 46 of the Amendments.

d Where spaces are of the same numerical category and superscript d appears, a bulkhead or deck of the rating shown in the Tables is only required when the adjacent spaces are for a different purpose, e.g. in category (9). A galley next to a galley does not require a bulkhead but a galley next to a paint room requires an "A-0" bulkhead.

e Bulkheads separating the wheelhouse, chartroom and radio room from each other may be "B-0" rating.

f A-0 rating may be used if no dangerous goods are intended to be carried or if such goods are stowed not less than 3 m horizontally from such bulkhead.

g For cargo spaces in which dangerous goods are intended to be carried, Regulation 54.2.8 of the Amendments applies.

h Bulkheads and decks separating Ro-Ro cargo spaces shall be capable of being closed reasonably gastight and such divisions shall have "A" class integrity in so far as is reasonable and practicable.

i Fire insulation need not be fitted if the machinery space in category (7) has little or no fire risk.

* Where an asterisk appears in the Tables, the division is required to be of steel or other equivalent material but is not required to be of "A" class standard.

4.2.6 Deck Coverings

Primary deck coverings in accommodation spaces, service spaces and control stations should be of a type which will not readily ignite.

4.2.7 Protection of Stairways and Lift Trunks

To prevent the spread of fire, stairways should generally be of steel construction and, if serving more than two decks, enclosed by "A" class divisions with self-closing doors at all levels.

Where a stairway serves only two decks it need only be enclosed at one level by "B" class divisions and a door with positive means of closing.

Lift trunks, which if unprotected would provide a route for the fire to spread from one level to another, require to be enclosed by "A" class divisions.

4.2.8 Miscellaneous Items

Reference should be made to 4.1.8 except for the paragraph relating to "rooms containing furniture and furnishings of restricted fire risk" which is not applicable.

4.2.9 Means of Escape

Having addressed the prevention of the outbreak of fire in accommodation areas, IMO had then to consider means to protect the crew when escaping from all spaces at all levels which they normally occupy. The escape route to the embarkation deck should be as direct as possible, easy to find, clearly indicated, and not less than 760 mm clear width.

Two widely separated means of escape from each accommodation level are required, one of which is to be a stairway below the lowest open deck, the other may be a vertical ladder through an access hatch, and two stairways above. Corridors longer than 7 metres are not permitted if these have only one exit.

It is generally recognised that an engine room fire presents serious difficulties to crew trying to evacuate the space, particularly from a lower level. The regulations require that from the lowest level of the machinery space either a continuous steel fire shelter, insulated in accordance with Tables 8a and 8b, leading to a safe position outside the space, with self-closing doors at the lowest level and any other access level, or a steel door operable from both sides leading to a space which provides safe access to the open deck be provided. In addition, a second steel ladder leading to a door in the upper part of the space should be provided. Lifts should not be considered as forming a means of escape.

Aluminium floorplates in Category A machinery spaces and in other spaces with a high fire risk are not permitted.

4.2.10 Ventilation Systems

Reference should be made to Section 4.1.11 except that any reference to automatic fire dampers being required in ducts passing through "main vertical zones" is to be disregarded.

4.3 Special Provisions for Passenger and Cargo Ships

4.3.1 Special Requirements for Ships Carrying Dangerous Goods

The substantial increase in the carriage of dangerous goods by sea resulted in regulations being drafted in order to prevent injury to persons or damage to the ship. Regulations were first included in the International Convention for the Safety of Life at Sea 1960 which, among other things, recommended a study be set up to establish a unified international code for the carriage of dangerous goods by sea. This study subsequently produced the International Maritime Dangerous Goods Code (IMDG Code) to which reference should be made when applying the Amendments.

Dangerous goods are divided into the following classes:

Class 1	Explosives.
Class 2	Gases; compressed, liquefied or dissolved under pressure.
Class 3	Flammable liquids.
Class 4.1	Flammable solids.
Class 4.2	Flammable solids or substances liable to spontaneous combustion.
Class 4.3	Flammable solids or substances which in contact with water emit flammable gases.
Class 5.1	Oxidising substances.
Class 5.2	Organic peroxides.
Class 6.1	Poisonous (toxic) substances.
Class 6.2	Infectious substances.
Class 7	Radioactive substances.
Class 8	Corrosives.
Class 9	Miscellaneous dangerous substances.

In addition to complying with the requirements for cargo spaces in passenger ships and cargo ships, as appropriate, the following ship types and cargo spaces when carrying dangerous goods governs the application of Table 9a.

(i) Ships and cargo spaces not specifically designed for the carriage of freight containers but intended for the carriage of dangerous goods in packaged form including goods in freight containers and portable tanks.

(ii) Purpose built container ships and cargo spaces intended for the carriage of dangerous goods in freight containers and portable tanks.

(iii) Ro/Ro ships and Ro/Ro cargo spaces intended for the carriage of dangerous goods.

(iv) Ships and cargo spaces intended for the carriage of solid dangerous goods in bulk.

(v) Ships and cargo spaces intended for the carriage of dangerous goods other than liquids and gases in bulk in shipborne barges.

The following requirements should govern the application of Tables 9a, 9b and 9c to both "on deck" and "under deck" stowage of dangerous goods.

4.3.1.1 Water Supplies

1 The fire main should be permanently pressurised or the fire pumps fitted with remote starting facilities.

2 The position of the hydrants is to be such that four jets of water, not emanating from the same hydrant, two of which must be from a single length of hose, may be directed to any part of the cargo space when empty. The total capacity is to be not less than 50 m^3/hour and the minimum pressure at each hydrant 0.27 N/mm^2, except for cargo ships less than 6000 gross tonnage when the minimum pressure may be 0.25 N/mm^2.

3 Means are to be provided to effectively cool the cargo space by a fixed pressure water spraying system. The number and arrangement of nozzles should be such as to ensure an effective average distribution of water of at least 4 litres per square metre per minute of deck area. This capacity should be considered as additional to any requirements for normal water fire fighting purposes. Alternatively the cargo space cooling may be effected by flooding the hold with water. The drainage and pumping arrangements should be such as to prevent the build up of free surfaces in the cargo space, or the possible adverse effect on stability due to the additional weight and free surface should be considered.

4 As an alternative to the water spraying system a high expansion foam system may be fitted with a discharge rate of 1 metre in depth per minute to the largest space.

Table 9a—Application of the requirements to different modes of carriage of dangerous goods in ships and cargo spaces

Wherever "x" appears in Table 9a it means that this requirement is applicable to all classes of dangerous goods as given in the appropriate line of Table 9c, except as indicated by the notes.

Section 4.3.1	.1	.2	.3			.4	.5
Section 4.3.1	Not specifically designed	Container cargo spaces	Closed Ro-Ro cargo spaces	Open Ro-Ro cargo spaces	Weather decks	Solid dangerous goods in bulk	Shipborne barges
.1.1	x	x	x	x	x	For application of requirements of Section 4.3.1 to different classes of dangerous goods—see Table 9b.	x
.1.2	x	x	x	x	x		—
.1.3	x	x	x	x	—		x
.1.4	x	x	x	x	—		x
.2	x	x	x	x	—		x[d]
.3	x	x	x	—	—		x[d]
.4.1	x	x[a]	x	—	—		x[d]
.4.2	x	x[a]	x	—	—		x[d]
.5	x	x	x	—	—		—
.6.1	x	x	x	x	x		—
.6.2	x	x	x	x	x		—
.7	x	—	—	x	x		—
.8	x	x[b]	x	x	x		—
.9	—	—	x[c]	x	—		—

NOTES:

a For classes 4 and 5.1 not applicable to closed freight containers. For classes 2, 3, 6.1 and 8 when carried in closed freight containers the ventilation rate may be reduced to not less than two air changes. For the purpose of this requirement a portable tank is a closed freight container.

b Applicable to decks only.

c Applies only to closed Ro-Ro cargo spaces, not capable of being sealed.

d In the special case where the barges are capable of containing flammable vapours or alternatively if they are capable of discharging flammable vapours to a safe space outside the barge carrier compartment by means of ventilation ducts connected to the barges, these requirements may be reduced or waived.

Table 9b—Application of the requirements to different classes of dangerous goods for ships and cargo spaces carrying solid dangerous goods in bulk

Class Section 4.3.1	4.1	4.2	4.3[f]	5.1	6.1	8	9
.1.1	x	x	—	x	x[g]	x[g]	x
.1.2[e]	x	x	—	x	—	—	x
.2	x	x[g]	x	x[g]	—	—	x[g]
.4.1[h]	x[g]	x[g]	x	x[g]	—	—	x[g]
.4.2[h]	x	x[g]	x	x[g]	—	—	x[g]
.6	x	x	x	x	x	x	x
.8	x	x	x	x[g]	x[g]	x[g]	x

NOTES:

e This requirement is applicable when the characteristics of the substance call for large quantities of water for fire fighting.

f The hazards of substances in this class which may be carried in bulk are such that special consideration must be given to the construction and equipment of the ships involved in addition to those enumerated in this Table.

g Reference is made to the International Maritime Dangerous Goods Code (resolution A.81(IV) as amended) or the Code of Safe Practice for Solid Bulk Cargoes (resolution A.434(XI) as amended), as appropriate.

h At least natural ventilation is required in enclosed cargo spaces intended for carriage of solid dangerous goods in bulk. In cases where power ventilation is required in the Code of Safe Practice for Solid Bulk Cargoes (resolution A.434(XI) as amended), the use of portable ventilation units (equipment) may suffice.

Table 9c—Application of the requirements to different classes of dangerous goods except solid dangerous goods in bulk

Class Section 4.3.1	1	2	3	4	5.1	5.2	6.1	8
.1.1	x	x	x	x[p]	x	x[p]	x	x
.1.2[i]	x	x	x	x[p]	x	x[p]	—	—
.1.3	x[k]	—	—	—	—	—	—	—
.1.4	x[k]	—	—	—	—	—	—	—
.2	x[k]	x[l]	x[m]	—	—	—	x[m, p]	x[m, p]
.3	x	x	x	x	x	—	x	x
.4.1	—	x[j]	x[m]	x[p]	x[p]	—	x[m, p]	x[m, p]
.4.2	—	x[l]	x[m]	—	—	—	x[m, p]	x[m, p]
.5	—	—	x[m]	—	—	—	x[n]	x[m]
.6	—	x	x	x	x	x[p]	x	x
.7	—	—	x	x	x	x[p]	x[p]	x[p]
.8	x[k, o]	x	x	x	x[p]	—	x[p]	x[p]
.9	x	x	x[m]	x[p]	x	—	x[m]	x[m]

NOTES:

i This requirement is applicable when the characteristics of the substance call for large quantities of water for fire fighting.

j Applicable to flammable or poisonous gases.

k Except goods of class 1 in division 1.4, compatibility group S.

l All flammable gases.

m All liquids having a flashpoint below 23°C (closed cup test).

n Liquids only.

o Goods of class 1 shall be stowed 3 m horizontally away from the machinery space boundaries in all cases.

p Reference is made to the International Maritime Dangerous Goods Code (resolution A.81(IV) as amended) or the Code of Safe Practice for Solid Bulk Cargoes (resolution A.434(XI) as amended), as appropriate.

For Class 1 Cargoes—Explosives—steam smothering should not be used. Gas smothering is ineffective

For Class 3 Cargoes—Flammable liquids—a fine water spray or high-expansion foam system is extremely effective when dealing with a liquid fire.

4.3.1.2 Sources of Ignition

To prevent the possibility of ignition of flammable vapours in enclosed cargo spaces, closed vehicle deck spaces or open vehicle deck spaces any electrical equipment and cables located therein are to be of a certified safe type.

4.3.1.3 Detection System

A fire detection and fire alarm system is to be fitted to all cargo spaces including closed vehicle deck spaces. Where samples of atmosphere are drawn from such cargo spaces provision is to be made to prevent the discharge of contaminated atmosphere through the sampling system into the space in which the detection apparatus is located. A notice should be prominently and permanently displayed at the equipment informing that samples are to be discharged in a safe location when carrying cargoes giving off toxic fumes.

4.3.1.4 Ventilation

1 In each enclosed cargo space an effective power ventilation system should be provided, having a capacity to give at least six air charges per hour, based on the empty cargo space, and for removal of vapours from the upper and lower parts of the cargo space.

2 The fans should be such as to avoid the possibility of ignition of flammable gas air mixtures. Suitable wire mesh guards are to be fitted over inlet and outlet ventilation openings.

4.3.1.5 Bilge Pumping

Where it is intended to carry flammable or toxic liquids in enclosed cargo spaces the bilge pumping system is to be designed to ensure against inadvertent pumping of such liquids through machinery space pumps or piping.

4.3.1.6 Personnel Protection

1 Four sets of full protective clothing resistant to chemical attack are to be provided. Each set should cover all the skin so that no part of the body is unprotected.

2 In addition, two self-contained breathing apparatuses should be provided. This personnel protection is additional to the fireman's outfits required for normal fire fighting duties.

4.3.1.7 Portable Fire Extinguishers

A minimum of two, six kilogramme, dry powder extinguishers stowed adjacent to the cargo space entrance are to be provided. These extinguishers are additional to those required for normal fire fighting purposes.

4.3.1.8 Insulation of Machinery Space Boundaries

Bulkheads forming boundaries between cargo spaces and machinery spaces of category A are to be insulated to "A-60" class unless the dangerous goods are stowed at least 3 metres horizontally away from the bulkheads except Class 1 goods which require additional "A-60" insulation between cargo spaces and machinery spaces of category A. Other boundaries between such spaces should be insulated to "A-60" class.

4.3.1.9 Water Spray System

Each open Ro-Ro cargo space having a deck above it and each closed Ro-Ro cargo space not capable of being sealed is to have a fixed water pressure spraying system for manual operation suitable for protecting all parts of any deck and vehicle platform in the space. The number and arrangement of nozzles should be such as to ensure an effective average distribution of at least 5 litres per square metre per minute of deck or platform area. This capacity is to be considered as additional to any requirements for normal water fire fighting requirements. The drainage and pumping arrangements must be capable of preventing the build up of free surfaces in the cargo spaces, or the possible adverse effect on stability due to the additional weight and free surface must be considered.

4.3.1.10 Document of Compliance

The special requirements for ships carrying dangerous goods are not a classification matter but for statutory purposes will require the issue of a special certificate referred to as a Document of Compliance. This document does not form part of the Safety Construction Certificate or Safety Equipment Certificate.

If blank forms of the Document of Compliance are not available to the surveyor then a factual Report 10 could be issued stating the extent of compliance of the construction and equipment pending further instruction from Headquarters.

4.3.2 Ventilation Systems in Special Category Spaces, Closed Ro-Ro Cargo Spaces and Cargo Spaces other than Ro-Ro Cargo Spaces Intended for the Carriage of Motor Vehicles with Fuel in their Tanks for their own Propulsion

To prevent the accummulation of flammable vapours in enclosed spaces on vessels which carry motor vehicles with fuel in their tanks for their own propulsion, a power ventilation system which can supply and exhaust the space is to be provided.

In special category spaces for ships carrying more than 36 passengers the power ventilation system should be capable of providing at least 10 air changes per hour and in all other spaces 6 air changes per hour. The system is to be entirely separate from any other ventilation system and ducts serving each cargo space are to be capable of being effectively sealed from any other space and controlled from a position outside the cargo spaces. The position of supply and exhaust openings are to be such as to prevent air stratification and the formation of air pockets.

Means are to be provided to indicate on the navigating bridge any loss or reduction of the required ventilating capacity. This can be achieved by gauging the pressure through a flow sensor on the discharge side of the fan.

The system should be capable of rapid shutdown and effective closure in the event of fire.

4.4 Oil Tankers and Combination Carriers

Oil tankers by the very nature of their cargo are potentially dangerous particularly during loading or discharging, tank cleaning, and whilst manoeuvring in port when the risk of collision is ever present. The regulations consequently require an effective and practical degree of fire protection by separating the accommodation spaces from the engine room, pump room and the cargo tank area by thermal and structural boundaries. To minimise the possibility of ignition of cargo vapour within cargo and slop tanks, an inert gas system may be required. To deal with cargo spillages on deck and fire in ruptured tanks, a fixed deck foam system is required.

4.4.1 Location and Separation of Spaces

Category A machinery spaces should be isolated from cargo tanks and slop tanks by a cofferdam, cargo pump room or oil fuel bunker tank and positioned aft of cargo tanks, slop tanks, cargo pump rooms and cofferdams though not necessarily aft of the bunker tanks.

The separation of accommodation spaces, main cargo control stations, control stations and service spaces is to be achieved by locating them aft of all cargo tanks, slop tanks cargo pump rooms and cofferdams. Any common bulkhead which separates the accommodation spaces, control stations and service spaces from the pump room is to be constructed to "A-60" standard. In order to protect the accommodation area from a fire on the tank deck the fronts of superstructures or deckhouses are to be insulated to "A-60" standard. This insulation must also be carried around the sides for 3 metres from the front boundary and is to include any overhang but, since the wheelhouse front and sides are surrounded by glass, insulation of this space is not required. However, the space should be gas and vapour tight. To further protect the accommodation spaces, service spaces and control stations, no air inlets or openings, including doors are permitted in boundaries which face the cargo area nor for a distance around the sides of at least L/25 from the front boundary, where L/25 is to be not less than 3 metres and need not be more than 5 metres. However, doors could be permitted provided they do not give access to the above mentioned spaces and all boundaries are insulated to "A-60" standard. Port lights fitted within the limits previously stated should be fixed and in the first tier provided with internal deadlights.

It should be noted that the regulations only require the structure to be "insulated to 'A-60' standard", that is, only the insulating material need satisfy the "A-60" temperature requirement.

Where the bulkhead between the engine room and the pump room is penetrated by cargo pump shafts, cables and pipes to oil content monitoring equipment and cables to pump room lighting, then approved glands or transit devices must be used.

To keep deck spills away from accommodation areas, a 150 mm high steel coaming, or similar, extending from side to side of the deck should be fitted immediately aft of the aftermost opening on the cargo tank deck.

Enclosed spaces are not permitted on the cargo tank deck except that small deckhouses may be permitted for the stowage of cargo oil hoses provided the ventilation arrangements are such as to ensure that pockets of flammable vapours cannot accumulate therein.

4.4.2 Structure

The hull, superstructure, structural bulkheads, decks and deckhouses should be constructed of steel or other equivalent material. Aluminium alloy may be used in the construction, however, due to its low melting point and resultant loss of structural integrity its use is limited to that given in 4.1.1.

The crowns and casings of machinery of Category A are to be of steel construction, adequately insulated, and any openings suitably arranged and protected to prevent the spread of fire.

4.4.3 Structural Fire Protection

The 1974 SOLAS requirements for structural fire protection in tankers were considerably more stringent than that required for dry cargo ships. However, it was recognised that some deficiencies still existed and as a consequence the 1981 Amendments have improved the standards and require, among other things, virtually all materials to be non-conbustible.

All internal divisional bulkheads are to be non-combustible "A", "B" or "C" class divisions. In accommodation and service spaces and control stations all ceilings, linings and draught stops are also to be non-combustible materials. A fixed fire detection and fire alarm system complying with 3.10 is to be installed to provide smoke detection and in addition manually operated call points in all corridors, stairways and escape routes within accommodation spaces are to be provided.

It is clearly necessary that fire divisions require to have openings in them for doors, ventilation, trunks, pipes and electric cables. Since any fire division can only be as good as its weakest part these penetrations must be of equivalent fire integrity to that of the division they penetrate.

4.4.4 Fire Integrity of Bulkheads and Decks

The minimum fire integrity of bulkheads and decks should be as prescribed in Tables 10a and 10b.

Table 10 Classification of spaces according to fire risk

The number in parentheses preceding each category refers to the applicable column or row number in the Tables.

(1) *Control stations*
Spaces containing emergency sources of power and lighting.
Wheelhouse and chartroom.
Spaces containing the ship's radio equipment.
Fire-extinguishing rooms, fire control rooms and fire-recording stations.
Control room for propulsion machinery when located outside the machinery space.
Spaces containing centralized fire alarm equipment.

(2) *Corridors*
Corridors and lobbies.

(3) *Accommodation spaces*
Spaces as defined in Glossary, excluding corridors.

(4) *Stairways*
Interior stairways, lifts and escalators (other than those wholly contained within the machinery spaces) and enclosures thereto. In this connection, a stairway which is enclosed only at one level shall be regarded as part of the space from which it is not separated by a fire door.

(5) *Service spaces (low risk)*
Lockers and store-rooms having areas of less than 2 m^2, drying rooms and laundries.

(6) *Machinery spaces of category A*
Spaces as defined in Glossary.

(7) *Other machinery spaces*
Spaces as defined in Glossary excluding machinery spaces of category A.

(8) *Cargo pump rooms*
Spaces containing cargo pumps and entrances and trunks to such spaces.

(9) *Service spaces (high risk)*
Galleys, pantries containing cooking appliances, paint and lamp rooms, lockers and store-rooms having an area of 2 m^2 or more, workshops other than those forming part of the machinery spaces.

(10) *Open decks*
Open deck spaces and enclosed promenades having no fire risk. Air spaces (the space outside superstructures and deckhouses).

Table 10a Fire integrity of bulkheads separating adjacent spaces; tankers and combination carriers

Spaces		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Control stations	(1)	A-0[c]	A-0	A-60	A-0	A-15	A-60	A-15	A-60	A-60	*
Corridors	(2)		C	B-0	A-0[a] B-0	B-0	A-60	A-0	A-60	A-0	*
Accommodation spaces	(3)			C	A-0[a] B-0	B-0	A-60	A-0	A-60	A-0	*
Stairways	(4)				A-0[a] B-0	A-0[a] B-0	A-60	A-0	A-60	A-0	*
Service spaces (low risk)	(5)					C	A-60	A-0	A-60	A-0	*
Machinery spaces of Category A	(6)						*	A-0	A-0[d]	A-60	*
Other machinery spaces	(7)							A-0[b]	A-0	A-0	*
Cargo pump rooms	(8)								*	A-60	*
Service spaces (high risk)	(9)									A-0[b]	*
Open decks	(10)										—

Table 10b Fire integrity of decks separating adjacent spaces; tankers and combination carriers

Space below ↓ Space above →		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Control stations	(1)	A-0	A-0	A-0	A-0	A-0	A-60	A-0	—	A-0	*
Corridors	(2)	A-0	*	*	A-0	*	A-60	A-0	—	A-0	*
Accommodation spaces	(3)	A-60	A-0	*	A-0	*	A-60	A-0	—	A-0	*
Stairways	(4)	A-0	A-0	A-0	*	A-0	A-60	A-0	—	A-0	*
Service spaces (low risk)	(5)	A-15	A-0	A-0	A-0	*	A-60	A-0	—	A-0	*
Machinery spaces of Category A	(6)	A-60	A-60	A-60	A-60	A-60	*	A-60[e]	A-0	A-60	*
Other machinery spaces	(7)	A-15	A-0	A-0	A-0	A-0	A-0	*	A-0	A-0	*
Cargo pump rooms	(8)	—	—	—	—	—	A-0[d]	A-0	*	—	*
Service spaces (high risk)	(9)	A-60	A-0	A-0	A-0	A-0	A-60	A-0	—	A-0[b]	*
Open decks	(10)	*	*	*	*	*	*	*	*	*	—

NOTES:

a For clarification as to which applies, *see* Regulations 43 and 46 of the Amendments.

b Where spaces are of the same numerical category and superscript b appears, a bulkhead or deck of the rating shown in the Tables is only required when the adjacent spaces are for a different purpose, e.g. in category (9). A galley next to a galley does not require a bulkhead but a galley next to a paint room requires an "A-0" bulkhead.

c Bulkheads separating the wheelhouse, chartroom and radio room from each other may be "B-0" rating.

d Bulkheads and decks between cargo pump rooms and machinery spaces of category A may be penetrated by cargo pump shaft glands and similar glanded penetrations, provided that gastight seals with efficient lubrication or other means of ensuring the permanence of the gas seal are fitted in way of the bulkhead or deck.

e Fire insulation need not be fitted if the machinery space in category (7) has little or no fire risk.

* Where an asterisk appears in the Tables, the division is required to be of steel or other equivalent material but is not required to be of "A" class standard.

4.4.5 Doors

All doors and their frames and the means of securing them when closed are required to provide a resistance to fire, as far as practicable, equivalent to that of the bulkhead in which they are situated. Where fitted in engine room casing bulkheads, they should be self-closing without any hold-back facility.

4.4.6 Insulation of "A" and "B" Class Divisions

Reference should be made to 4.1.4 and Figures 12a to 12k.

4.4.7 Deck Coverings

Primary deck coverings in accommodation spaces, service spaces and control stations should be of a type which will not readily ignite.

4.4.8 Protection of Stairways and Lift Trunks

To prevent the spread of fire, stairways should generally be of steel construction and, if serving more than two decks, enclosed by "A" class divisions with self-closing doors at all levels. Where a stairway serves only two decks it need only be enclosed at one level by "B" class divisions and a door with positive means of closing.

Lift trunks which, if unprotected, would provide a route for the fire to spread from one level to another require to be enclosed by "A" class divisions.

4.4.9 Miscellaneous Items

Reference should be made to 4.1.8, except for the paragraph relating to "rooms containing furniture and furnishings of restricted fire risk" which is not applicable.

4.4.10 Means of Escape

Having addressed the prevention of the outbreak of fire in accommodation areas IMO had then to consider means to protect the crew when escaping from all spaces at all levels which they normally occupy. The escape route to the embarkation deck should be as direct as possible, easy to find, clearly indicated, and not less than 760 mm clear width.

Two widely separated means of escape from each accommodation level are required, one of which is to be a stairway below the lowest open deck, the other may be a vertical ladder through an access hatch, and two stairways above. Corridors longer than 7 metres are not permitted if these have only one exit.

It is generally recognised that an engine room fire presents serious difficulties to crew trying to evacuate the space, particularly from a lower level. The regulations require that from the lowest level of the machinery space either a continuous steel fire shelter, insulated in accordance with Tables 10a and 10b, leading to a safe position outside the space, with steel self-closing doors at the lowest and any other access level, or a steel door operable from both sides leading to a space which provides safe access to the open deck be provided. In addition a second steel ladder leading to a door in the upper part of the space should be provided.

Lift trunks should not be considered as forming one of the means of escape.

Aluminium floorplates in category A machinery spaces and in other spaces with a high fire risk are not permitted.

4.4.11 Ventilation Systems

Reference should be made to Section 4.1.11 except that any reference to automatic fire dampers being required in ducts passing through "main vertical zones" is to be disregarded.

4.4.12 Venting, Purging, Gas Freeing and Ventilation

The safe dispersal of flammable vapours from the cargo tanks of oil tankers poses a considerable problem and many serious tank explosions have occurred due to the passage of flame through the venting system after ignition of the flux by an external source.

These systems are intended to deal with the flow via pressure/vacuum valves of small volumes of vapour, air or inert gas mixtures caused by thermal variations and the passage of large volumes of such gases during cargo loading and discharge, during ballasting operations, or when gas freeing.

The venting arrangements may constitute independent stand pipes for each tank or branches from each tank connected by a common main, which may be the inert gas main, into a mast riser. In the latter case means are required for isolating cargo tanks.

The venting systems should be entirely distinct from the air pipes of the other compartments of the ship. The position of openings in the cargo tank deck from which emission of flammable vapours could occur should be such as to minimise the possibility of flammable vapours being admitted to enclosed spaces containing a source of ignition or collecting in the vicinity of deck machinery and equipment which may constitute an ignition hazard. Reference should be made to the Regulations concerning the minimum distance of openings from an ignition hazard.

Arrangements for purging and/or gas freeing should be such as to minimise the hazards due to the dispersal of flammable vapours in the atmosphere and to flammable mixtures in a cargo tank.

The venting system is required to be provided with devices to prevent the passage of flame into the tanks and SOLAS requires that the design, testing and locating of these devices comply with approved standards which must meet at least the standards which have been adopted by IMO. These standards are much more stringent than hitherto but could be met by flame arrestors or high velocity vent heads. It is considered that the use of wire mesh flame screens will be limited in future.

The tests prescribed include a flash-back test for flame arrestors located at the openings to the atmosphere and additionally, an endurance burning test for flame arrestors at outlets where flows of explosive vapour are foreseeable. There are also test procedures for detonation flame arrestors located in-line and test procedures for high velocity vents.

Operational test procedures prescribed include a corrosion test and a hydraulic pressure test.

Cargo pump rooms are to be mechanically ventilated and discharges from the exhaust fans led to a safe space on the open deck. The position of openings in deckhouse or superstructure boundaries should be considered in relation to the pump room ventilation openings. Cargo spaces and adjacent enclosed spaces in combination carriers are to be mechanically ventilated. In addition, a fixed gas warning system capable of monitoring flammable vapours should be provided in cargo pump rooms, pipe ducts and cofferdams adjacent to slop tanks. Arrangements should be made to facilitate measurement of flammable vapours in all other spaces within the cargo tank area.

The subject of cargo tank venting, purging gas freeing and ventilation is very complex and considered by the authors to be outside their expertise. Its brief inclusion in this paper is necessary because it is a vital element of fire protection for tankers, however, it could well be the subject of a future paper for the Lloyd's Register Technical Association.

4.4.13 Cargo Tank Protection

The protection of accommodation spaces, etc., and the methods to reduce the possibility of flammable vapours accumulating on the tank deck or adjacent enclosed spaces has previously been discussed. Consideration should now be given

to what is known as cargo tank protection, a heading which may be slightly confusing since reference is made to a fire prevention system and a fire extinction system.

The regulations require the cargo tanks deck area and cargo tanks on all tankers to be protected by a fixed deck foam system complying with 3.7.2. In addition all tankers and combination carriers above 20 000 tonnes deadweight are to be provided with an inert gas system complying with 3.9.

All tankers operating with a cargo tank cleaning procedure using crude oil washing must also be fitted with an inert gas system.

Tankers fitted with a fixed inert gas system should be provided with a closed ullage system.

4.4.14 Cargo Pump Rooms

Cargo pump rooms are to be provided with either a CO_2, halon, high expansion foam or water spray system. Reference should be made to Figure 3 for the detailed requirements.

Cargo pump rooms may be illuminated by permanent gastight lighting enclosures in bulkheads or decks separating them from other spaces.

4.5 Miscellaneous

4.5.1 Ships provided with a Helicopter Landing Area with or without Fuelling Facilities

Adjacent to the means of access to any helicopter landing area the following fire fighting equipment should be stored ready for use:

(a) Dry powder extinguishers of total capacity not less than 45 kilogrammes.

(b) A suitable foam applicator system which should consist of monitors or foam making branch pipes capable of delivering foam solution at a rate of not less than 6 litres per minute per square metre of the area contained within a circle of diameter D metres for not less than five minutes. D is the distance across the main rotor and tail rotor in the fore and aft line of a helicopter with a single main rotor and across both rotors for a tandem rotor helicopter.

(c) Carbon dioxide extinguishers of total capacity of not less than 16 kilogrammes. These are to be equipped as to enable the medium to be applied to the engine area of any helicopter using the deck.

The arrangement of water service pipes, hydrants, hoses and nozzles is to be such that at least two jets of water may reach any part of the helicopter deck and, where helicopter refuelling facilities are provided, any part of the fuel storage tanks and associated pumps and piping.

In every ship provided with helicopter refuelling facilities at least two portable extinguishers, suitable for fighting oil fires, should be provided adjacent to the fuel storage tanks and associated pumps and piping in addition to any other portable extinguishers required.

5. GLOSSARY OF TERMS

Accommodation spaces are those spaces used for public spaces, corridors, lavatories, cabins, offices, hospitals, cinemas, games and hobbies rooms, barber shops, pantries containing no cooking appliances and similar spaces.

Bulkhead deck is the uppermost deck up to which the transverse watertight bulkheads are carried.

Cargo area is that part of the ship that contains cargo tanks, slop tanks and cargo pump rooms including pump rooms, cofferdams, ballast and void spaces adjacent to cargo tanks and also deck areas throughout the entire length and breadth of the part of the ship over the above-mentioned spaces.

Cargo spaces are all spaces used for cargo (including cargo oil tanks) and trunks to such spaces.

Closed Ro-Ro cargo spaces are Ro-Ro cargo spaces which are neither open Ro-Ro cargo spaces nor weather decks.

Combination carrier is a tanker designed to carry oil or alternatively solid cargoes in bulk.

Continuous "B" class ceilings or linings are those "B" class ceilings or linings which terminate only at an "A" or "B" class division.

Control stations are those spaces in which the ship's radio or main navigating equipment or the emergency source of power is located or where the fire recording or fire control equipment is centralized.

Crude oil is any oil occurring naturally in the earth whether or not treated to render it suitable for transportation and includes:

(a) crude oil from which certain distillate fractions may have been removed; and

(b) crude oil to which certain distillate fractions may have been added.

Dangerous goods are those goods referred to in Section 4.3.

Deadweight is the difference in tonnes between the displacement of a ship in water of a specific gravity of 1.025 at the load waterline corresponding to the assigned summer freeboard and the lightweight of the ship.

Low flame spread means that the surface thus described will adequately restrict the spread of flame, this being determined by an established test procedure.

Machinery spaces are all machinery spaces of Category A and all other spaces containing propulsion machinery, boilers, oil fuel units, steam and internal combustion engines, generators and major electrical machinery, oil filling stations, refrigerating, stabilizing, ventilation and air conditioning machinery, and similar spaces, and trunks to such spaces.

Machinery spaces of Category A are those spaces and trunks to such spaces which contain:

(a) internal combustion machinery used for main propulsion; or

(b) internal combustion machinery used for purposes other than main propulsion where such machinery has in the aggregate a total power output of not less than 375 kW; or

(c) any oil-fired boiler or oil fuel unit.

Main vertical zones are those sections into which the hull, superstructure, and deckhouses are divided by "A" class divisions, the mean length of which on any deck does not in general exceed 40 metres.

Oil fuel unit is the equipment used for the preparation of oil fuel for delivery to an oil-fired boiler, or equipment used for the preparation for delivery of heated oil to an internal combustion engine, and includes any oil pressure pumps, filters and heaters dealing with oil at a pressure of more than 0.18 N/mm^2.

Open Ro-Ro cargo spaces are Ro-Ro cargo spaces either open at both ends, or open at one end and provided with adequate natural ventilation effective over their entire length through permanent openings in the side plating or deckhead.

Public spaces are those portions of the accommodation which are used for halls, dining rooms, lounges and similar permanently enclosed spaces.

Rooms containing furniture and furnishings of restricted fire risk are, for the purpose of Section 4.1, those rooms containing furniture and furnishings of restricted fire risk (whether cabins,

public spaces, offices or other types of accommodation) in which:

(a) all case furniture such as desks, wardrobes, dressing tables, bureaux, dressers, is constructed entirely of approved non-combustible materials, except that a combustible veneer not exceeding 2 mm may be used on the working surface of such articles;

(b) all free-standing furniture such as chairs, sofas, tables, is constructed with frames of non-combustible materials;

(c) all draperies, curtains and other suspended textile materials have qualities of resistance to the propagation of flame not inferior to those of wool of mass 0.8 kg/m^2*;

(d) all floor coverings have qualities of resistance to the propagation of flame not inferior to those of an equivalent woollen material used for the same purpose;

(e) all exposed surfaces of bulkheads, linings and ceilings have low flame-spread characteristics; and

(f) all upholstered furniture has qualities of resistance to the ignition and propagation of flame.

N.B.*Reference is made to Recommendation on Test Method for Determining the Resistance to Flame of Vertically Supported Textiles and Films, adopted by resolution A.471(XII).

Ro-Ro cargo spaces are spaces not normally subdivided in any way and extending to either a substantial length or the entire length of the ship in which goods (packaged or in bulk, in or on rail or road cars, vehicles (including road or rail tankers), trailers, containers, pallets, demountable tanks or in or on similar stowage units or other receptacles) can be loaded and unloaded normally in a horizontal direction.

Service spaces are those spaces used for galleys, pantries containing cooking appliances, lockers, mail and special rooms, store-rooms, workshops other than those forming part of the machinery spaces, and similar spaces and trunks to such spaces.

Special category spaces are those enclosed spaces above or below the bulkhead deck intended for the carriage of motor vehicles with fuel in their tanks for their own propulsion, into and from which such vehicles can be driven and to which passengers have access.

Steel or other equivalent material. Where the words "steel or other equivalent material" occur, "equivalent material" means any non-combustible material which, by itself or due to insulation provided, has structural and integrity properties equivalent to steel at the end of the applicable exposure to the standard fire test (e.g. aluminium alloy with appropriate insulation).

Weather deck is a deck which is completely exposed to the weather from above and from at least two sides.

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BIBLIOGRAPHY

1. Prevention, Detection and Fighting of Ship's Fires, British Ship Research Association.
2. The Manual of Firemanship, Parts 1 and 7, Her Majesty's Stationery Office.
3. Survey of Fire Appliances (Instruction to Surveyors) Her Majesty's Stationery Office.
4. Fire Protection Handbook, The National Fire Protection Association.
5. Fire Protection, Detection, and Extinction in Ships, G. Coggon, L.R. Technical Association Paper No. 1, Session 1974-75.
6. Fire Detection in Unattended Machinery Spaces, J. D. Bolding, L.R. Technical Association Paper No. 3, Session 1970-71.
7. Inert Gas Systems, I.M.O., 1983 Edition.

APPENDIX A
FIRE TESTING

Before examining the requirements for structural fire protection for any ship, there are some important aspects to be defined:

(1) The Standard Fire Test, IMO Resolution A517 (13) 17/11/83

(2) Non-combustibility, IMO Resolution A472 (XII) 19/11/81

(3) Surface spread of flame, IMO Resolution A166 (ES IV) 28/11/68

(4) Primary deck coverings, IMO Resolution A214 (VII) 12/10/71

It is not uncommon for certificates concerning the above to be misunderstood, particularly non-combustibility and surface spread of flame, certificates for which are constantly being presented to the Society as Standard Fire Test certificates which they *definitely are not*.

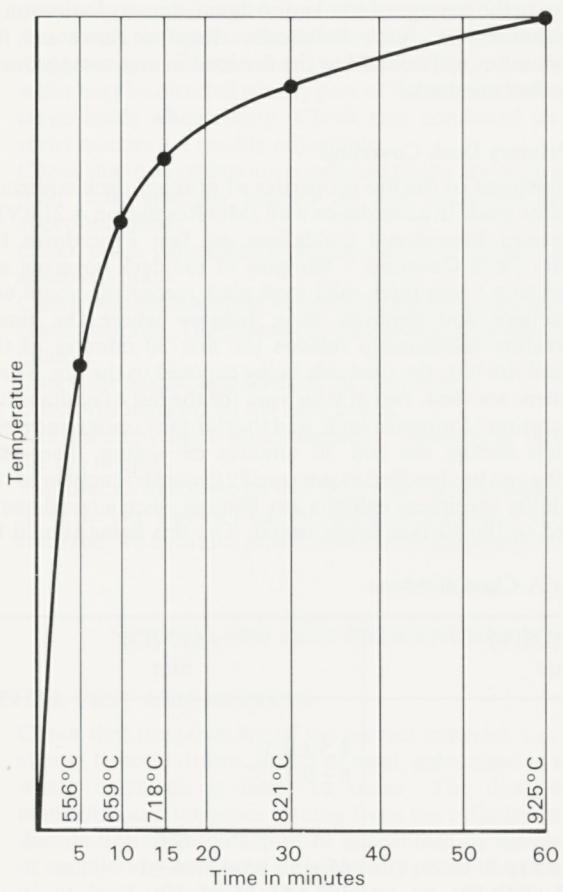


Fig. A.1 Standard fire test curve

1. Standard Fire Test

This is a test in which specimens of materials which are intended to be used in the construction of fire bulkheads and decks are exposed to a fire whose development is regulated according to the standard time/temperature relationship as shown in Figure A1.

The specimens are approximately 4,65 m^2 in area and have a height of 2,44 metres but may be larger. They must resemble as closely as possible the construction of the actual division to be used on the ship and include, where appropriate, at least one joint.

The Society requires that for A-Class divisions the specimen should have the steel side exposed to the fire if general approval is required (i.e. fire to either side), since a test with the insulated face exposed to the fire would result in limited certification for the tested system for use only where it could be established that the greatest fire risk would be on the insulated side (i.e. inside engine casings or outside stairwell casings).

Similarly when doors are being tested the door and frame should be installed in the test bulkhead with the door opening outwards away from the fire. It is obvious that a door and frame assembly, when tested and certified together, can not have either part substituted by another door or frame without a further fire test to demonstrate the validity of the substitution.

The testing period of one hour for A-Class divisions is based on the SOLAS concept that the effects of a fully developed fire on a ship, which may be beyond the capability of the crew to deal with, could be contained within the structural fire protection bulkheads for one hour which *should* give ample time to accomplish safe abandonment of the ship. The testing period for B-Class divisions is half an hour. B-Class divisions are used as boundaries of corridors forming escape routes thus these should give sufficient time for evacuation of the area immediately adjacent to a fire.

2. Non-Combustible Materials

These are materials which neither burn, nor give off flammable vapour in sufficient quantity for self-ignition when heated to approximately 750 deg.C.

It will be seen that non-combustibility is not an absolute term, but only applies below the temperature stated. It is quite possible for a material which burns at temperatures above 750 deg.C to be referred to as non-combustible, provided it complies with the above definition.

Non-combustible materials are inorganic, although not all inorganic materials are non-combustible. Organic materials cannot be rendered non-combustible by any known treatment, whether by the application of surface coatings or impregnated with chemicals. Although such treatments may reduce the susceptibility to ignition and retard the development of a fire, they neither reduce the combustion contents nor significantly affect the process of decomposition under heat. Eventually, flammable vapours are given off and little difference is made to the combustibility in a fully developed fire.

All organic materials and all plastics as they are at present known, are combustible by this standard.

3. Surface Spread of Flame

Examination of IMO Resolution A166 (ES IV) will show that a unified international standard method of testing could not be agreed and that the national test method commonly used for building materials in each administration's country will be deemed acceptable.

In the U.K. this is BS 476 Part 7 which gives gradings as Class 1, 2, 3 and 4. Low flame spread as required by the SOLAS Regulations and the Rules would be Class 1 or 2.

4. "A" Class Divisions

"A" Class Divisions are those divisions formed by bulkheads and decks which comply with the following:

(i) they shall be constructed of steel or other equivalent material;

(ii) they shall be suitably stiffened;

(iii) they shall be so constructed as to be capable of preventing the passage of smoke and flame to the end of the one-hour standard fire test;

(iv) they shall be insulated with approved non-combustible materials such that the average temperature of the unexposed side will not rise more than 139 deg.C above the original temperature, nor will the temperature, at any one point, including any joint, rise more than 180 deg.C above the original temperature, within the time listed below:

Class "A-60"	60 minutes
Class "A-30"	30 minutes
Class "A-15"	15 minutes
Class "A-0"	0 minutes

(v) the administration may require a test of a prototype bulkhead or deck to ensure that it meets the above requirements for integrity and temperature rise.

As a footnote to Chapter II-2, Regulation 3, of the Convention reference is made to IMO Assembly Resolution A.163 (ESIV), Recommendation for Fire Test Procedures for "A" and "B" Class Divisions. This was superseded on the 17th November, 1983, by Resolution A517(13). Table A.1 shows the comparison of minimum scantlings required to achieve A-Class for each of the Resolutions.

Insulation materials for use on A-Class divisions which were fire tested and approved using the scantlings of Resolution A163(ESIV) will remain acceptable for use on A-Class divisions as defined by Resolution A517(13).

5. "B" Class Divisions

"B" Class Divisions are those divisions formed by bulkheads, decks, ceilings or linings which comply with the following:

(i) They shall be so constructed as to be capable of preventing the passage of flame to the end of the first one-half hour of the standard fire test.

(ii) They shall have an insulation value such that the average temperature of the unexposed side will not rise more than 139 deg. C above the original temperature, nor will the temperature at any one point including any joint, rise more than 225 deg. C above the original temperature, within the time listed below:

Class "B-15"	15 minutes
Class "B-0"	0 minutes

(iii) They shall be constructed of approved non-combustible materials and all materials entering into the construction and erection of "B" Class divisions shall be non-combustible, with the exception that combustible veneers may be permitted provided they meet the other requirements of Chapter II-2.

(iv) The administration may require a test of a prototype division to ensure that it meets the above requirements for integrity and temperature rise.

It should be noted that the combustible B-30 Class bulkhead, permissible in previous Conventions for certain applications, is no longer acceptable for use as a required fire division in any ship type constructed to comply with the 1981 Amendments.

6. "C" Class Divisions

"C" Class Divisions are divisions constructed of approved non-combustible materials. They need meet no requirements relative to the passage of smoke and flame, nor any limitation of temperature rise. Such bulkheads therefore have no fire resistance but will not add to the fire load in any compartment where they are used.

7. Primary Deck Coverings

Assessment of the fire properties of primary deck coverings should be made in accordance with IMO Resolution A 214(VII) "Improved Provisional Guidelines on Test Procedures for Primary Deck Covering". Samples of the deck covering are applied to a 5 mm thick mild steel plate measuring about 600 mm square and exposed to a furnace where the time/temperature relationship follows the first 30 minutes of the standard fire test, the steel side being exposed to the fire. Three specimens are used, two of which are for the test of ignitability, test duration 15 minutes each, and the third for smoke and toxic products during the full 30 minutes of testing. The deck covering can be classified as *not readily ignitable* if neither of the ignitability specimens exhibits any flaming when a test flame is applied to the surface being tested. The test flame should be

Table A.1 Minimum scantlings for A-Class divisions

Resolution	A163 (ESIV) mm	A517 (13) mm
BULKHEADS		
Plate thickness—steel	4 to 6	4.5 ± 0.5
—aluminium	6 to 8	6 ± 0.5
Stiffeners		
Spacing—steel and aluminium	700 ± 100	600
Scantlings—steel	$70 \pm 10 \times 70 \pm 10 \times 5$ to 7	$65 \pm 5 \times 65 \pm 5 \times 6 \pm 1$
Scantlings—aluminium	$100 + 10 \times 75 + 10 \times 8$ to 10	$100 \pm 5 \times 85 \pm 5 \times 0 \pm 1$
DECKS		
Plate thickness—steel	4 to 6	4.5 ± 0.5
—aluminium	6 to 8	6 ± 0.5
Beams		
Spacing—Steel and aluminium	700 ± 100	600
Scantlings—Steel	$100 \pm 10 \times 75 \pm 10 \times 6$ to 8	$100 \pm 5 \times 70 \pm 5 \times 8 \pm 1$
Scantlings—aluminium	$150 \pm 10 \times 90 \pm 10 \times 8$ to 10	$150 \pm 5 \times 100 \pm \times 9 \pm 1$

applied at one minute intervals throughout the testing. The quantity of smoke and toxic products given off are to be recorded but no criteria have been established for acceptable limits, this being left to the satisfaction of the administration having jurisdiction.

8. Fire Test for Fire Main Fittings

The Society considers that valves, cocks and other fittings having materials which could be readily rendered ineffective by heat are not acceptable in fire main systems unless they can withstand a suitable fire test as follows:

(i) Test Procedure
The valve or other item to be tested should be placed in a suitable furnace or oven where a temperature of 540 deg. C should be maintained for 20 minutes, during which time an internal water pressure, without flow, of 8.3 bars should be maintained on the item. At the end of the test the leakage should not exceed 22.7 litres per minute.

(ii) Test Conditions
Hydrants, valves and cocks should be tested in the closed position. Hydrants should be tested with the outlet hose connection open, (i.e. with no cap on). Isolating valves and similar valves and cocks should be tested with pressure on one side of the valve or cock and may have an open ended pipe connected to the other side of the valve or cock leading outside the furnace.

(iii) Exemptions
Valves having metal to metal valve lids and seats, and cocks having metal bodies and plugs, are normally acceptable without a fire test.

Compressed asbestos fibre jointing not thicker than 1.6 mm, and other jointings not thicker than 0.8 mm, may be accepted without test, except neoprene and other materials with similar melting points.

APPENDIX B

SURVEY AND TEST PROCEDURES FOR THE FIRE MAIN

INITIAL INSPECTIONS

1. Check hydrant positions and hose positions and that the nozzles are stowed with the hoses together with any tools necessary for their operation. These should be in accordance with the approved plan, but as such plans are often diagrammatic, the surveyor should verify that two jets of water may be directed on any part of the ship including the cargo holds when empty. Check that combined jet and spray nozzles are readily adjustable.
2. Check that no systems are connected to the fire main other than those specially catered for and permitted by the approved plans.
3. Check drain valves and isolating valves as shown on the approved plans.
4. Check that all manifold valves are readily accessible and clearly marked. They should be sited reasonably near to the pumps.
5. Check the length and diameter of the hoses.
6. Check the marking of the hose boxes.
7. Run the fire pumps simultaneously, discharging through the fire main.
8. Test that an adequate jet can be produced simultaneously from the two highest hydrants using each pump singly, or from the two hydrants most remote from the pump if in the Surveyor's opinion that would be more onerous.
9. Run the pumps with the fire main and all systems connected to it operating simultaneously and check that the jets required by foregoing item (1) can be produced.
10. Ensure that the relief valves are set to operate properly, and discharge to a suitable location.
11. Check the starting of the emergency fire pump and test it discharging to all parts of the fire main outside the compartment containing the main fire pumps.
12. Check the international shore connections.

PERIODIC INSPECTIONS

1. Run each fire pump and check that the pumping capacity is adequate. Check the starting of the emergency fire pump.
2. Examine all hoses. They should be ranged, including those which look new. Pay particular attention to the attachment of the hoses to the couplings. Run water through each hose at pressure and check for leaks.
3. Ensure that water is flowing and that the couplings are undamaged.
4. Examine the fire main, paying particular attention to the joints. Operate the isolating valves.
5. Check the nozzles and the international shore connections and any tools required for connecting the hose.
6. Check the marking of the hose boxes.

APPENDIX C

SURVEY AND TEST PROCEDURES FOR CARBON DIOXIDE AND HALON FIXED SYSTEMS

INITIAL TEST AND SURVEYS

1. Check that the pipes are of the correct material, i.e. they should be solid drawn, and if of steel, galvanised in areas where corrosion is likely to occur. The distribution manifolds and the pipes leading from the cylinders to the distribution manifolds must be guaranteed by the makers or suppliers to have been satisfactorily tested to a pressure of at least 125 bars. The makers or suppliers must guarantee that not less than 10 per cent of the pipes from the distribution manifolds to the spaces being protected have been satisfactorily tested to a hydraulic pressure of at least 125 bars. In cases where the national authority of the country of registry of the ship has other standards for the quality and testing of the piping, these will generally be accepted.

   If led through insulated spaces, the pipes should be fitted with suitable drainage arrangements, located at the lowest point of the pipe and, if terminating in a refrigerated space, at each nozzle.

   All joints should be made by suitable barrel couplings, cone connections or flanges. Screwed and running couplings are not allowed. After installation test all joints with either CO_2 gas, compressed air, or for a halon system with freon, to a pressure of about 6 bars with the discharge opening closed. Ensure all plugs are removed from the discharge openings after testing. The piping should extend at least 5 cm beyond the last nozzle.
2. Check the arrangement of discharge heads, sizes and types with the approved plans. Ensure the nozzles are positioned clear of ladderways, walkways, doorways, etc. such that the discharge would not endanger personnel evacuating the protected space.
3. Check that dirt traps and drain traps are fitted.
4. Check the number of cylinders and that they are fully charged, fitted with a safety disc and stamped with the weights when empty and full, the name of the contents, test

pressure, date and place of testing and stamped by the official testing authority. The weight of liquid must not exceed two thirds of a kilogramme for each kilogramme of water capacity of the cylinder.

The safety discs should be a type which will burst at:

(a) for CO_2 systems; 190 bar ± 5 per cent

(b) for halon 25 bar systems; 68 bar ± 5 per cent

(c) for halon 42 bar systems; 88 bar ± 5 per cent.

In a gang release system non-return valves should be fitted in the pipes leading from the cylinders to enable the cylinders to be disconnected without affecting the effective use of the other cylinders of the system.
Check that the cylinders are properly mounted and secured and the gang release system, if any, is connected correctly.
Check that the length of syphon tubes when fitted and secured have a clearance between the end of the tube and the inner surface of the bottom which is not excessive. The bottom end of the tube should be cut at an angle of 45° and the tube secured tight by locking compound or similar. If a remote control is fitted the system should also be capable of operation entirely from within the cylinder room. In a halon system with the containers located inside the protected space, ensure the duplicate power release lines required are as remote as practicable from each other inside the protected space.If electrically activated the cables are to be mineral insulated or if hydraulically or pneumatically activated the pipes are to be of steel or equivalent material.

5. The remote controls, local controls and automatic release controls, if fitted, should be operated.
6. Check the operation of the gas release delay mechanism and the automatic means to stop ventilating fans serving the protected spaces and closing of all openings.
7. Check that there is a relief valve fitted in the distribution manifold.
8. Check and test the automatic alarms (audible and visual) fitted to signal the impending discharge of medium into the protected spaces. This should preferably be carried out during sea trials when the engines, auxiliaries and cargo pumps are running at full power to ensure the alarms will be audible at all times.
9. Check the ventilating arrangements in the cylinder room.
10. Check the lighting arrangements in the cylinder room. They should be connected to the main and emergency supplies.
11. Check that the instructions for operation of the system are clearly displayed adjacent to each control position.

PERIODICAL SURVEYS AND TESTS

1. Examine the cylinders for corrosion or damage and check the number. They should be weighed or the level of liquid gauged, at least once every four years. Cylinders do not normally require to be pressure tested for classification purposes, except where considered necessary by the attending surveyor. However, some national authorities require periodic hydraulic testing of the cylinders and reference should be made to the Instructions to Surveyors.
2. Check that the cylinders are connected to the manifold and properly mounted and secured and that the syphon tube is screwed tight and secured with a locking compound or similar.
3. Examine the release mechanism.
4. Blow through the system with compressed air and ensure that air is discharged satisfactorily from each discharge nozzle (particular attention should be paid to those CO_2 nozzles discharging over the engine room bilges).
5. Test the visible and audible alarms which, if gas operated, should be tested with compressed air; such air should be clean and dry if discharged into the cargo pump room of an oil tanker.
6. Check that the dirt and drain traps are free.
7. Check the operation of the delay mechanism.
8. Check that the operating instructions are displayed adjacent to the control positions.
9. Where possible these tests should be carried out by a reliable specialist and witnessed by the attending surveyor.

SURVEY AND TEST PROCEDURES FOR CO_2 AND HALON LOW PRESSURE BULK STORAGE SYSTEMS

1. In addition to the foregoing the following procedure should be adopted for the inspection of installations.
2. The storage tank is to be examined internally and externally. In a CO_2 installation provided the insulation is not damaged and the surveyor is satisfied from the general condition of the installation that significant external corrosion of the tank is unlikely to have occurred and that the tank is in otherwise sound condition it will not be necessary to remove any insulation for closer inspection of the tank.
3. If it is considered necessary to make a closer inspection of the tank containing CO_2 requiring the removal of insulation the manufacturers of the storage facility should be consulted before the work is started and their advice obtained regarding the procedure to be adopted. If any difficulty is encountered in obtaining advice from the manufacturers the matter should be referred to Headquarters.
4. The level of liquid in the storage tank is to be checked. A loss of more than 5 per cent by weight of liquid is to be made good.
5. Control instrumentation and alarms pertinent to the maintenance of the CO_2 storage conditions are to be tested.
6. Storage tank relief valves are to be changed over at least every two years and the lifting pressure of the relief valves tested. Other relief valves in the filling and discharge lines are to be tested at least every four years.
7. Storage tanks should be internally examined at any time when they are empty provided that the interval between internal examinations does not exceed ten years. Tanks are to be thoroughly ventilated before entry. Where an installation has more than one storage tank and not all tanks have been emptied, suitable precautions should be taken to prevent the inadvertent admission of CO_2 or halon into the tanks opened up for examination.
8. In a CO_2 system each unit of the refrigeration installation serving the storage facility is to be examined under working conditions. The capability of each unit to maintain the contents of the storage tanks at the required temperature using main and emergency power supplies is to be verified.
9. Any safety cut-outs are to be tested. Earth continuity arrangements fitted to prevent the build up of static electricity are to be examined.

APPENDIX D

SURVEY AND TEST PROCEDURES FOR FIXED FOAM SYSTEMS

HIGH EXPANSION FOAM SYSTEMS

1. Check the pump and any change-over valves. These should be located in a readily accessible space outside the protected area.
2. Check the power supply to the fan. It should be supplied from the main and emergency sources.
3. Check that the screen is clean and intact.
4. Check any trunking and the operation of any valves in it.
5. Check the level of the foam concentrate.
6. Run the system using the foam sampling branch provided.
7. Check that the fan cuts out when the water supply is cut off.
8. Check that there is an operating manual available.

LOW EXPANSION DECK FOAM SYSTEM

1. Check the water pump and any change-over valves.
2. Check the piping system including any branches to permissible low demand systems.
3. Check the isolating valve on the branch from the fire main (if any).
4. Check the positions of the hydrants, hoses, applicators and monitors.
5. Check the capacity of the foam concentrate. If the concentrate is protein type it is recommended that it be tested by the manufacturer. If any replenishment is carried out, check that the correct type is supplied.
6. Check the water/foam proportionating system.
7. Run the system to check the range of the monitors and the quality of the foam. Flush through with water after this test.
8. Check that there is an operations manual readily available in the control room.

LOW EXPANSION MACHINERY SPACE SYSTEMS

1. Check that pump and control room are outside the protected space and readily accessible.
2. Check that the foam concentrate tank is full. There is no requirement for renewing old concentrate, but it is recommended that samples of protein foam liquid be sent to the supplier for testing at least every two years. If new foam concentrate is supplied it should be verified that it is the correct type (particularly in bulk chemical tankers).
3. Check that the pipes and nozzles are clear. In new systems this should be done by discharging foam. In existing systems, compressed air may be used.
4. Check the hydrants, hoses and foam applicators.
5. Check the height and water tightness of the coamings round the hazard areas.
6. Test the water/foam concentrate proportionating system in the control room.
7. Check that there is an operations instruction manual displayed in the control room.
8. The piping should always be flushed with water after foam has been used.

APPENDIX E

SURVEY AND TEST PROCEDURES FOR SPRINKLER SYSTEMS

1. Check sprinkler heads to ensure they have not been covered with paint, clogged with dirt, grease, rust etc or blanked off by subsequent fittings.
2. Check lamps are illuminating over the buzzer in the navigating bridge/fire control room alarm panel.
3. At each sprinkler station open the test valve in order to verify that the appropriate alarm in the navigating bridge/fire control room is operating. Additionally the main section check valve should be throttled in order to check the alarm. Ensure the valve is fully locked open after verifying the alarm.
4. Check that the valve at the cross-connection to the firemain is operating satisfactorily after which it should be locked shut.
5. Referring to Figure 4, test the automatic starting of the sprinkler pump by closing valves 1 and 11 and opening valve 12.
6. Check the air compressor and the safety devices for the air compressor and the pressure tank.
7. Check the fresh water supply to the pressure tank.

APPENDIX F

SURVEY AND TEST PROCEDURES FOR PORTABLE FIRE EXTINGUISHERS

1. All portable fire extinguishers should be examined at each annual and renewal safety equipment survey. If there is any sign of corrosion, leakage or damage the extinguisher concerned should be tested by discharging, cleaning, repairing as necessary, hydraulically testing and refilling.

   The instructions for use should be clearly marked on the wall of the canister and each type painted in accordance with Table 3.
2. Water (soda acid) with loose stopper acid bottle, water (stored pressure) and chemical foam extinguishers should be tested by discharging at least once every two years and the charge renewed.

   Water (soda acid) except with loose stopper acid bottle, water (gas cartridge), powder (gas cartridge) powder (stored pressure) field refillable type should be tested by discharging at least once every five years.

   After discharge the extinguisher should be examined for damage and corrosion and if such is found it should be cleaned and repaired as necessary and then tested to a hydraulic pressure of 1.5 times the working pressure or 21 bars whichever is the greater for dry powder extinguishers and the remainder to 21 bars before recharging.
3. Carbon dioxide extinguishers should be checked by weight and if a loss of more than 10 per cent of the contents or more than the percentage recommended by the manufacturers, if less than 10 per cent is detected, the extinguisher tested by discharging and refilled.

   If a cylinder is corroded or damaged, but in the opinion of the surveyor, based on a visual examination, not serious enough to warrant its rejection it should be subjected to a hydraulic test before recharging.

   All cylinders should be subjected to a hydraulic pressure test after ten years and subsequently after a further ten years and thereafter at intervals not exceeding five years.
4. Halon and dry powder (stored pressure) factory sealed type extinguishers should be tested by discharging and hydraulically testing after ten years and subsequently after a further ten years and thereafter at intervals not exceeding five years.
5. Water, chemical foam and dry powder extinguishers should be tested hydraulically to at least 21 bars once every four years.

APPENDIX G

SURVEY AND TEST PROCEDURES FOR BREATHING APPARATUS

1. AIR HOSE TYPE

1.1 Examine the face mask for its general condition paying particular attention to the securing straps and the connection of the air hose.

1.2 Examine the condition of the air hose and the foot pump bellows.

1.3 Test the assembled set worn by a man, that the air delivery to the face mask is adequate.

2. SELF-CONTAINED BREATHING APPARATUS

2.1 Examine the face mask for its general condition and particularly the straps for securing it to the head of the wearer and the condition of the visor.

2.2 Examine the condition of the tube from the reducing valve to the face mask.

2.3 Examine the condition of the air cylinders.

2.4 Connect each cylinder to the set and open the cylinder valve to check the pressure readings on the gauge. This should indicate that the cylinders are full by reference to the manufacturer's operations manual.

2.5 Get a man to wear the set and, with the face mask hanging free, gently open the by-pass valve or demand valve and ensure that air is discharged into the face mask; this should be clearly audible. Shut the valve.

2.6 With the man wearing the face mask, restrict the air supply by closing the cylinder valve, and the mask should collapse on the face after one or two breaths. Open the cylinder valve immediately.

2.7 With the face mask removed, close the cylinder valve and open the by-pass valve or demand valve and the warning whistle should sound as the air pressure falls.

2.8 All the above tests should be carried out under the direction of the responsible ship's officer who is to see that the set is properly cleaned, disinfected, dried and stowed on completion.

2.9 The method of effecting the above mentioned tests will vary according to the design of the apparatus. Reference should be made to the manufacturer's instruction manual.

APPENDIX H

LIST OF PLANS AND INFORMATION REQUIRED TO BE SUBMITTED FOR APPROVAL FOR ALL SHIPS INTENDED FOR THE SOCIETY'S CLASSIFICATION

1. FIRE PROTECTION

A statement of the method of structural fire protection adopted.

A general arrangement plan showing the main fire zones, escape stairways and the fire compartmentation bulkheads and decks within the main fire zones including the engine and boiler rooms, the galleys, paint stores, lamp rooms, navigating bridge, radio room, fire fighting control rooms, emergency generator rooms, battery locker.

A plan showing the details of construction of the fire protection bulkheads and decks and the particulars of any surface laminates employed.

A plan showing the construction of the fire doors.

A ventilation plan showing the ducts and any dampers in them, and the position of the controls for stopping the system.

A plan showing the sprinkler system and/or detection system, as applicable.

A plan showing the remote control for the fire doors, if applicable.

A plan showing the location and arrangement of the emergency stop for the oil fuel unit pumps and for closing the valves on the pipes from oil fuel tanks.

A plan of the fire alarm systems, if applicable.

2. FIRE EXTINGUISHING

A general arrangement plan showing the disposition of all the fire fighting equipment including the fire main, the fixed fire extinguishing systems in the cargo holds, on deck and in the machinery spaces, the disposition of the portable and non-portable extinguishers and the types used, the position and details of the firemen's outfits.

A plan showing the layout and construction of the fire main, including the main and emergency fire pumps, isolating valves, pipe sizes and materials, the international shore connections and the cross connections to any other systems.

A plan showing details of each fixed fire fighting system including calculations for the quantities of the media used and the proposed rates of application.

3. FIRE CONTROL PLANS

Every ship irrespective of age is required by the 1981 Amendments to SOLAS 1974 Chapter II, 2, Regulation 20, to have permanently exhibited for the guidance of the ship's officers, a fire control plan. A copy of this plan should be submitted for approval.

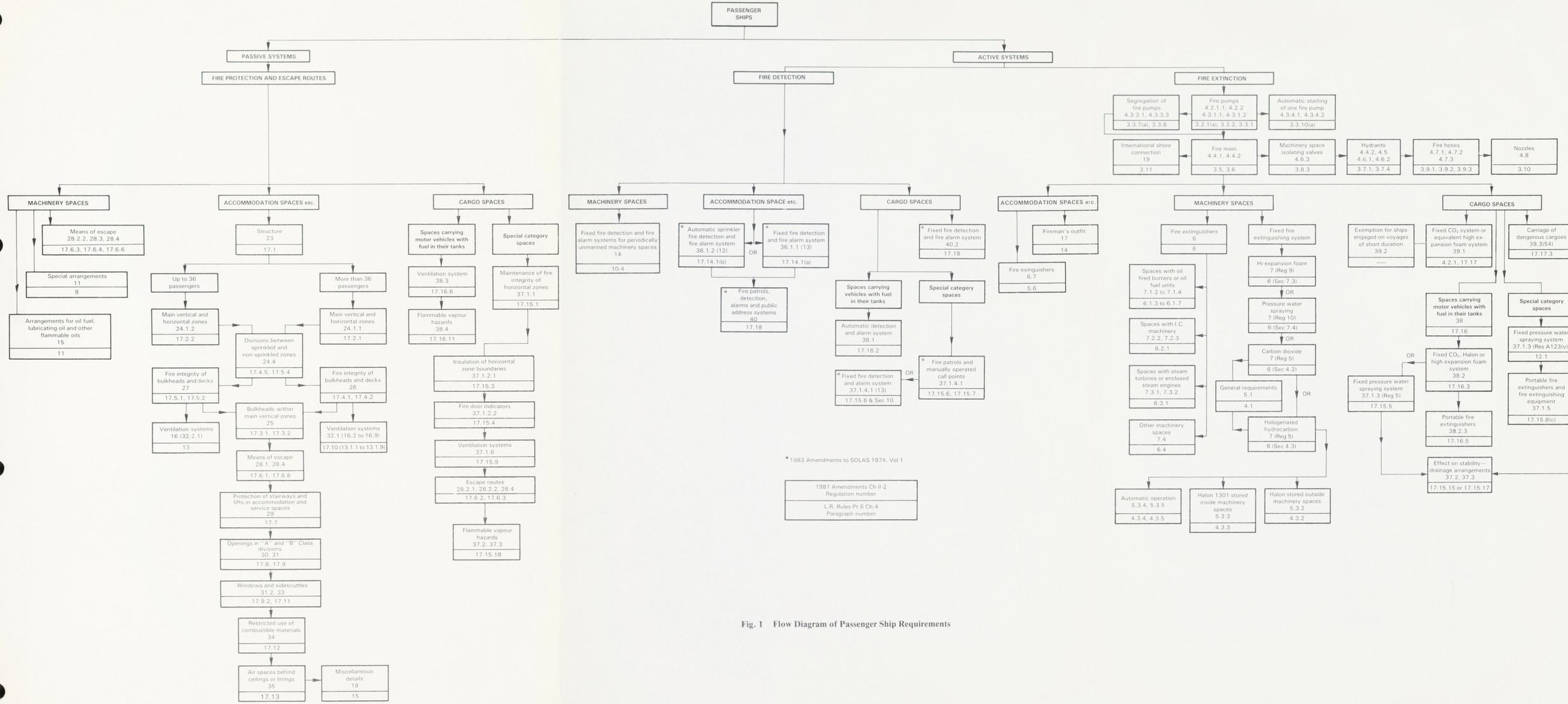
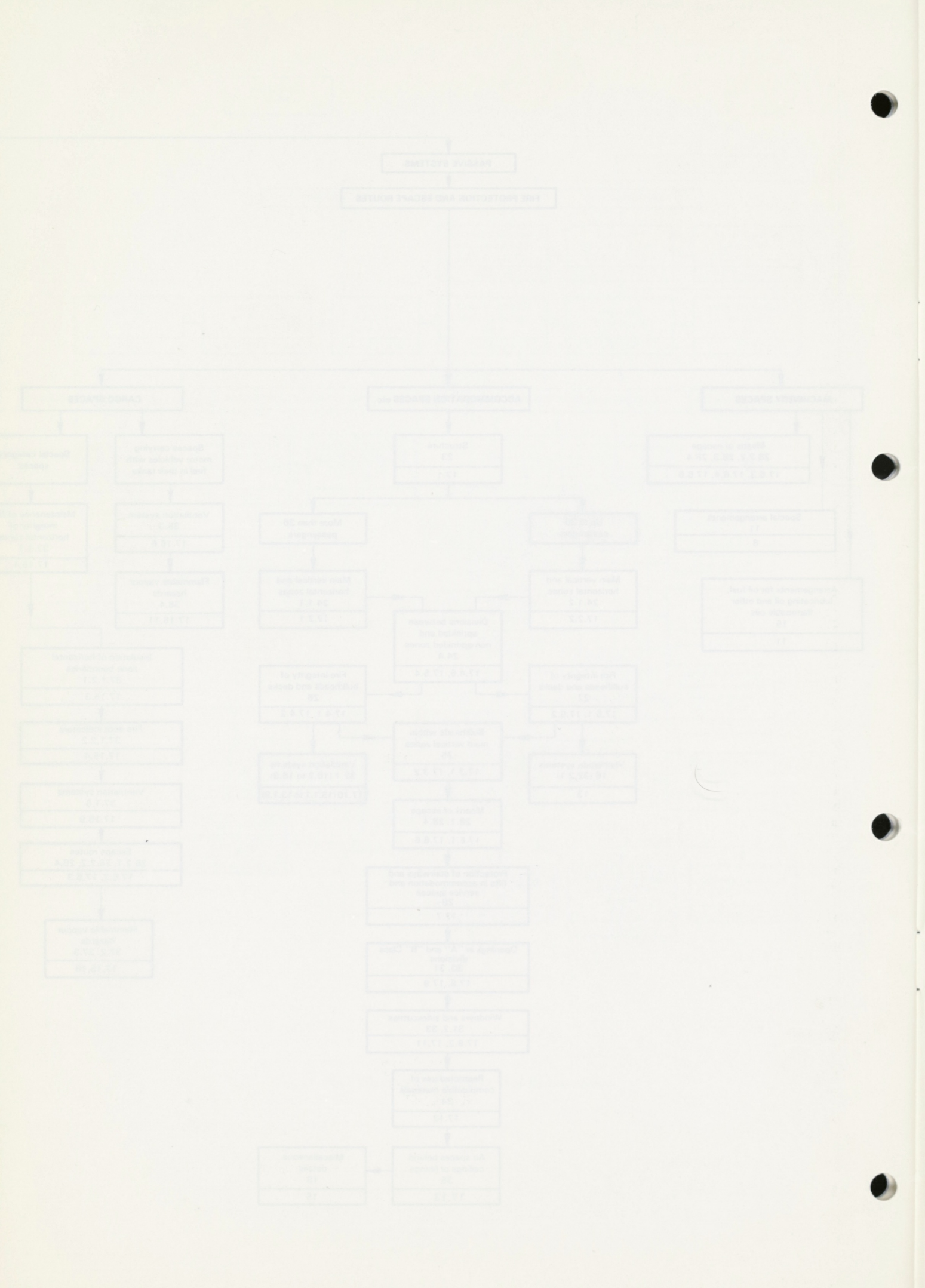


Fig. 1 Flow Diagram of Passenger Ship Requirements



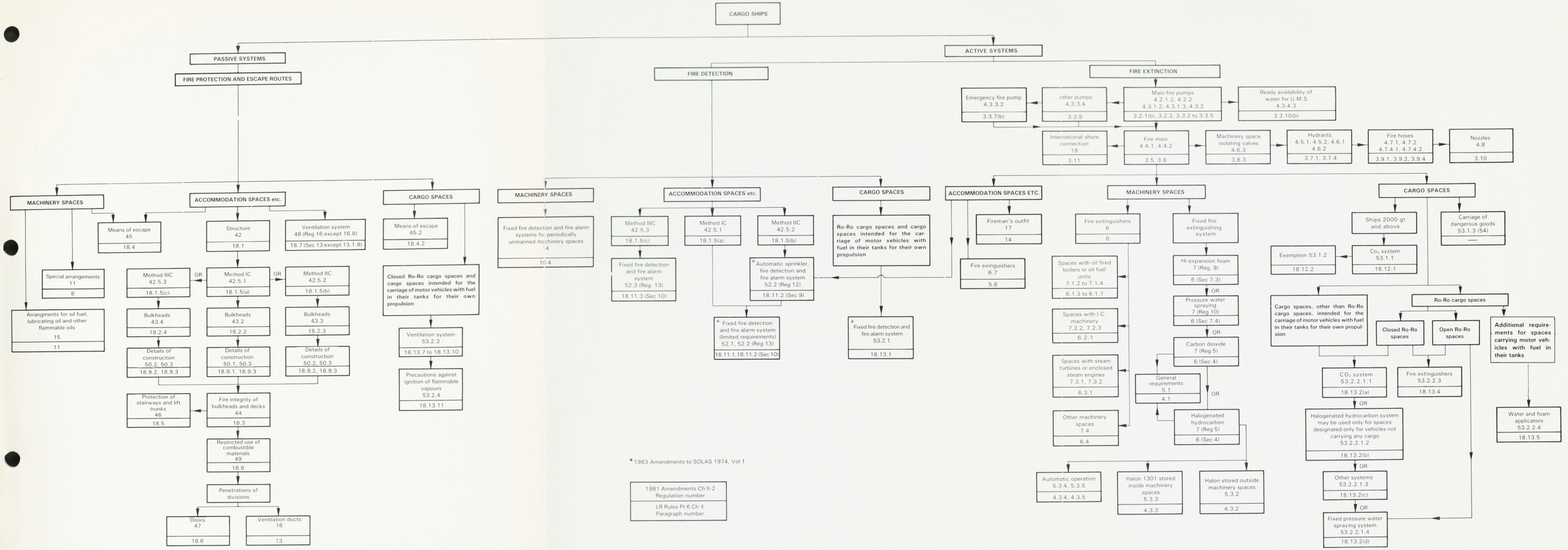


Fig. 2 Flow Diagram of Cargo Ship Requirements



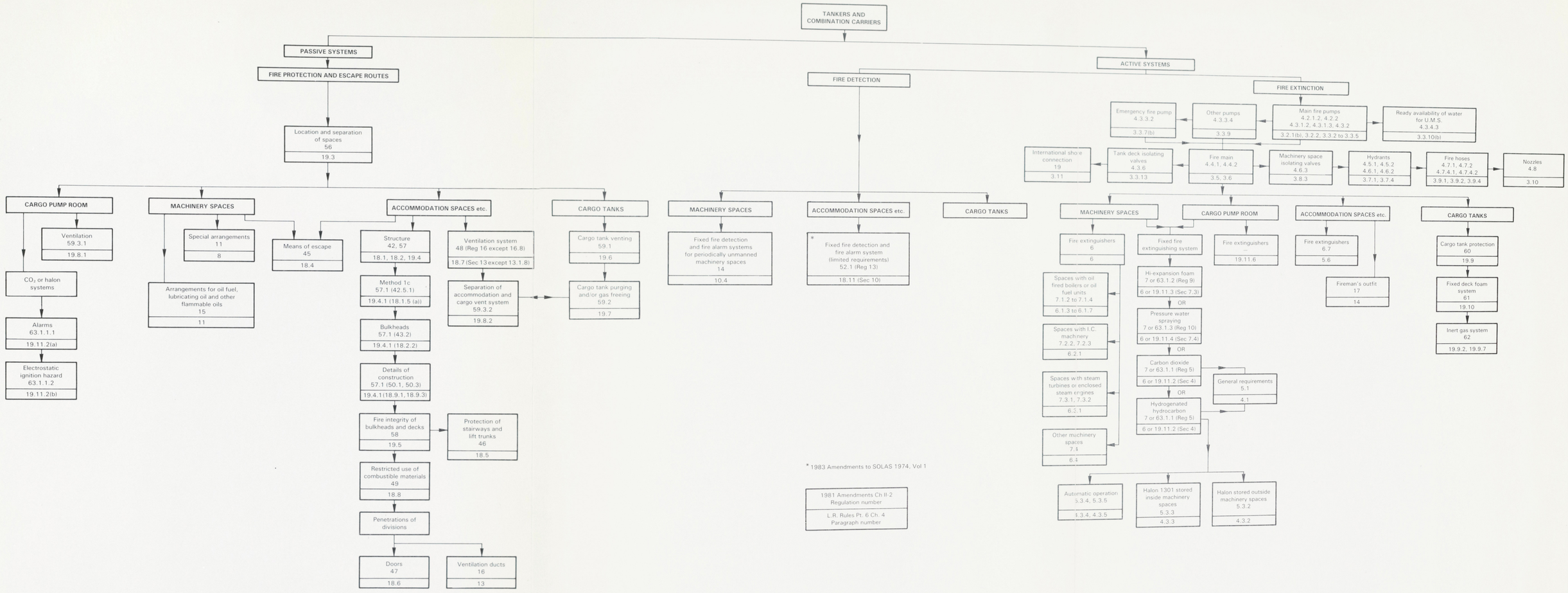


Fig. 3 Flow Diagram of Oil Tanker and Combination Carrier Requirements



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Discussion

on the paper

FIRE SAFETY ASPECTS OF THE 1981 AMENDMENTS TO SOLAS 1974

by

D. J. Holland and C. M. Magill

This Paper was awarded the 1984–85 L.R.T.A. Medal

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Any opinions expressed and statements made in this Discussion Paper are those of the individuals.

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Discussion on the Paper

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DISCUSSION

From Mr. G. Coggon:

First of all I would like to congratulate the Authors on a very good paper and to thank them for the many hours of effort which must have been necessary to produce it.

It is a bulky paper which is well written and presented. It is entirely practical in its scope and should be of great use to outside surveyors in their duties.

I was a little disappointed that for such a photogenic subject it had so few photographs, but it has lots of excellent diagrams and is packed full of useful information.

I had always intended to write the replacement for my paper on Fire Protection, Detection and Extinction in Ships and had decided that the time to do so would be when the 1981 Amendments to SOLAS '74 would come into force. I was, therefore, rather disappointed when Messrs. Holland and Magill asked if they could write it. However, I decided to let them do it. This was one of my better decisions and the Association has benefitted greatly because I couldn't have done such a good job. It is a really splendid paper and I am sure it will be well received by surveyors all over the world and will be frequently referred to over the coming years.

The paper refers to the development of marine fire protection in relation to the various types of ships, viz. Passenger, Tanker, Cargo and of the different parts of the ships such as the accommodation spaces and cargo area. It would appear that, since about 60% of fires now occur in the engine room, the next development could well be in that area.

If the authors agree with this, could they say what improvements might be expected? Also, whether we might expect any further development in relation to a particular type of ship?

I notice they have included sections on inert gas and cargo tank venting arrangements. Now our engineering colleagues may think these are rather superficial and perhaps should not be included because, of course, these are subjects which are dealt with in MDAPAD, but they had to be included since they are vital elements of fire protection in oil tankers. However, I notice the suggestion on page 43 that cargo tank venting could be the subject of a future paper. May I heartily endorse this, and suggest that the subject of the proposed paper might be extended to include inert gas systems as well. There is no doubt in my mind that such a paper is long overdue and the expertise is there to produce it.

From Mr. W. N. G. McCulloch:

The Authors must be thanked and, indeed congratulated, for so satisfactorily wending their weary way through the ever-increasing complexity of International Regulations governing shipboard fire safety; their Paper will be well received as a work of reference by all who are concerned in the design, submission, approval and survey of fire safety systems and arrangements.

As with Mr. Coggon's earlier Paper on the same subject, it will be of great value, particularly to younger colleagues, in its easy-to-read descriptive narrative on the various detection and extinction systems.

In the Port and District of London we have no major new building work in progress at the present time, and we are therefore not involved in initial installation and testing, but we are constantly conducting Periodical Surveys on a wide variety of ship types and sizes.

It will be appreciated, therefore, that the parts of the Paper which concern us most directly are the Appendices which give guidance in the conduct of periodical surveys and tests. These surveys and any required systems testing are carried out at the Mandatory Annual Survey, which should coincide with either the Annual or Renewal Safety Equipment Survey, or the Intermediate Survey in the case of tankers over ten years old.

The extent of the survey, in so far as fire-fighting equipment is concerned, is indicated on both the check-off list attached to Circular 2412, for classification, and the check-off list attached to Circular 2374, for Safety Equipment, and the question we have most difficulty in answering, with a clear conscience is "Were fixed fire-fighting system controls, piping, instructions and markings properly maintained and serviced?" We are asked to record the date of the last reported system test.

The maintenance of the system controls etc. is the responsibility of the ship-board personnel and the Surveyor might be able to satisfy himself regarding maintenance by requesting the responsible person to go over the system with him and explain his maintenance procedure. The servicing, I believe, should be carried out at established intervals by an accredited agent of the manufacturer.

So far as I am aware there is no requirement for frequency of servicing, and detailed maintenance and servicing requirements are rarely found on board. It is our view that our survey procedure for these installations should be directly related to approved maintenance procedures which should be contained in the Manufacturers's Instructions Booklet; we could then certify that maintenance had been so conducted, and logged.

So far as servicing and testing is concerned, we suggest that this should be carried out bienially and, as I have said, by an accredited agent of the manufacturer, and in accordance with an approved procedure. Towards this end, in submitting his proposed system for approval the Manufacturer should also submit his Maintenance and Service Manual, together with a list of his accredited Agents. Lists of Manufacturers, their approved system identification and their accredited Agents could then be microfiched in the same way as the list of liferaft and lifeboat service agents.

At the present time our Field Surveyor finds himself in a situation where the ship board personnel are frequently insufficiently familiar with the fixed fire-fighting installation, and are unable satisfactorily to demonstrate its continuing efficiency. The Surveyor is obliged to spend a great deal of time endeavouring to explain (very often to a member of the ship's staff whose mother tongue is not English), how the system should work, how it should be maintained and what tests, if any, should be conducted and how they should be conducted. Very few ships coming under our survey in London are attended by a responsible Superintendent, and very little, if any, pre-survey preparation is made.

In substantiation of these remarks and suggestions I have requested our Mr. David Woodcraft to join me this afternoon,

and relate, briefly one or two of his recent experiences and that of other colleagues, who operate in the eastern section of our Port. I should like to conclude by reiterating my submission that our Periodical Survey Procedure should be directly related to a Manufacturers Approved Maintenance and Servicing Manual, with servicing being carried out by accredited agents of the manufacturers at an agreed frequency.

From Mr. D. Woodcraft:

This week I had occasion to carry out an Annual Safety Equipment Survey on a Bulk Carrier during the course of which I requested testing of the remote-control operation of the quick-closing (Q.C.) valves to the oil fuel tanks. The Report S.E.1 showed these to be pneumatically operated. I was conducted by the Chief Engineer and Chief Officer (who had both been on board for over one month) to a red painted cabinet containing two small CO_2 bottles at the E.R. entrance. Alongside the cabinet were instructions in Japanese and in English which referred to the operation of the CO_2 fixed fire extinguishing system in the Engine Room and Cargo Holds! I was then informed that this was the cabinet for operating the Q.C. valves but that we couldn't test them as they had no spare bottles! At this stage I made no comment, but asked to see the CO_2 Room. On the way there we passed a control cabinet on the E.R. forward bulkhead which contained a small air bottle and control valves marked 'NORMAL' and 'EMERGENCY', but with no operating instructions. I asked the Chief Engineer what this was for and was informed that he knew in his own language but couldn't explain in English; eventually, through an interpreter, the Chief admitted he had no idea what it was for.

I was thus obliged to explain to the ship's Officers how their fixed CO_2 system and the Q.C. valve system were operated. Finally, suitable notices, in the national language of the ship's Officers, were drafted and posted at both cabinets. On this same ship, whilst examining the fire hoses, I noticed that one 60ft. hose had a bayonet connection at one end and an instantaneous at the other; hydrants and nozzles were all bayonet type.

The following comments are offered from colleagues who cannot be here today:

CO_2 Bottle Systems

1. During survey it was noted that the loose end of the release wire for the bottle bank, 30″ to 40″ long, was neatly fitted to a bulkhead bracket and securely fastened with a bulldog clip which effectively ensured the system would not operate.
2. On another ship the release mechanism and pilot bottle installation was such that upon operating the pilot bottles, the storage bottles were kept in the closed position.
3. Outlet funnels and discharge nozzles in cargo holds choked with bulk cargo residue and piping severely damaged.

Bulk CO_2 System

Broken glass level gauges to the storage tank are not uncommon and cannot easily be replaced. The manufacturers do not usually supply spares. In one such case, the approximate liquid level was guaged by the installation of a stand pipe in the piping system and noting the degree of moisture freezing on the outside of the pipe; a substantial loss of liquid from one tank had occurred without the ship's staff realising it.

Bulk Foam System

During a Change of Flag survey a leak on the low expansion foam tank inlet valve necessitated the overhaul of the valve, and the opportunity was taken to examine the tank contents. Consequently the tank had to be washed out and the foam replaced. A subsequent low pressure test of the system revealed a leakage on the tank shell which had previously been painted over, and this resulted in the complete loss of foam. It is considered that such pressure vessels should be examined and hydraulically tested at regular intervals, say every 5 and 6 years.

From Mr. B. W. Oxford:

As Ernie Wise might say "It must be a great privilege for the Authors to have me comment on this excellent and comprehensive paper".

Now I am here firstly to explain that time has flown once again and, through no fault of the Authors, the Diagram of an Inert Gas System shown on Page 19 needs to be updated slightly. The reason for this, as you will all be aware, is that Notice No. 2 of the 1984 Rules has completely changed the format of Part 5, Chapter 15, Section 7 of the Rules relating to inert gas systems although the content is much the same as it was before except for a few details. The reason for the change is a rationalisation exercise in changing our Rules to conform with Regulation 62 of the 1981 Amendments to SOLAS '74. I don't think that we should worry too much that, in following IMO's lead in this respect, the Society is in danger of losing its identity because, as the Authors have pointed out in the right-hand column of page 3, the Society exerts considerable influence at IMO through membership of working parties on various subjects and indeed we should be grateful in particular to some members of staff who take on the onerous task of chairmen of some of these working parties such as, in my personal experience, Mr. Coggon who was a very effective chairman of the working party on Devices to Prevent the Passage of Flames into Cargo Tanks.

Refering to Fig. D.1 which shows the current requirements of Part 5, Chapter 15, Section 7 of the Rules, there is one addition and one amendment that should be noted. The addition is the vent between the auto-closing bulkhead valve and the deck isolating valve. The purpose of this fitting is to prevent hydrocarbon gas from the cargo tanks from building up a pressure after the system has been shut down and the deck isolating valve closed. Opening this valve allows any gas to vent to atmosphere. With the vent located as shown the hydrocarbon gas pressure would have to build up to a pressure greater than a column of water 2.4 m high in the inlet pipe to the deck seal before it would be released and in my opinion it would be better to fit the vent either between the deck seal and non-return valve, in which case the non-return valve could be tested for leakage, or between the non-return valve and the deck isolating valve. In either of these positions, with the vent open and the deck isolating valve shut, there would be no possibility of pressure building up in the deck seal which could be a potential source of gas entry into the engine room via the deck seal water supply line.

The amendment refers to the cross-connection between the inert gas main and the cargo oil lines on deck. Since the design condition for the I.G. system is approximately 0.24 bar compared to say 16 bar in the cargo lines when discharging cargo, you can see that there is a great potential for the oil to leak into the I.G. system causing not only a terrible mess but also the danger that oil could pass back through the I.G. main into a safe area, and it is for this reason that the isolation between the two systems should not depend upon one valve but rather the option of having either two valves, with a vent in between, or a spool piece. When fitting the option of a spool piece it is debatable whether you also need the valves since the wording of the Rule is not completely clear but the implication is that you do still need the two valves since the Rule requires the valve nearest the cargo main to be of a non-return type.

At the risk of making my comments longer than the paper I just want to touch lightly, in fact very lightly, upon the question

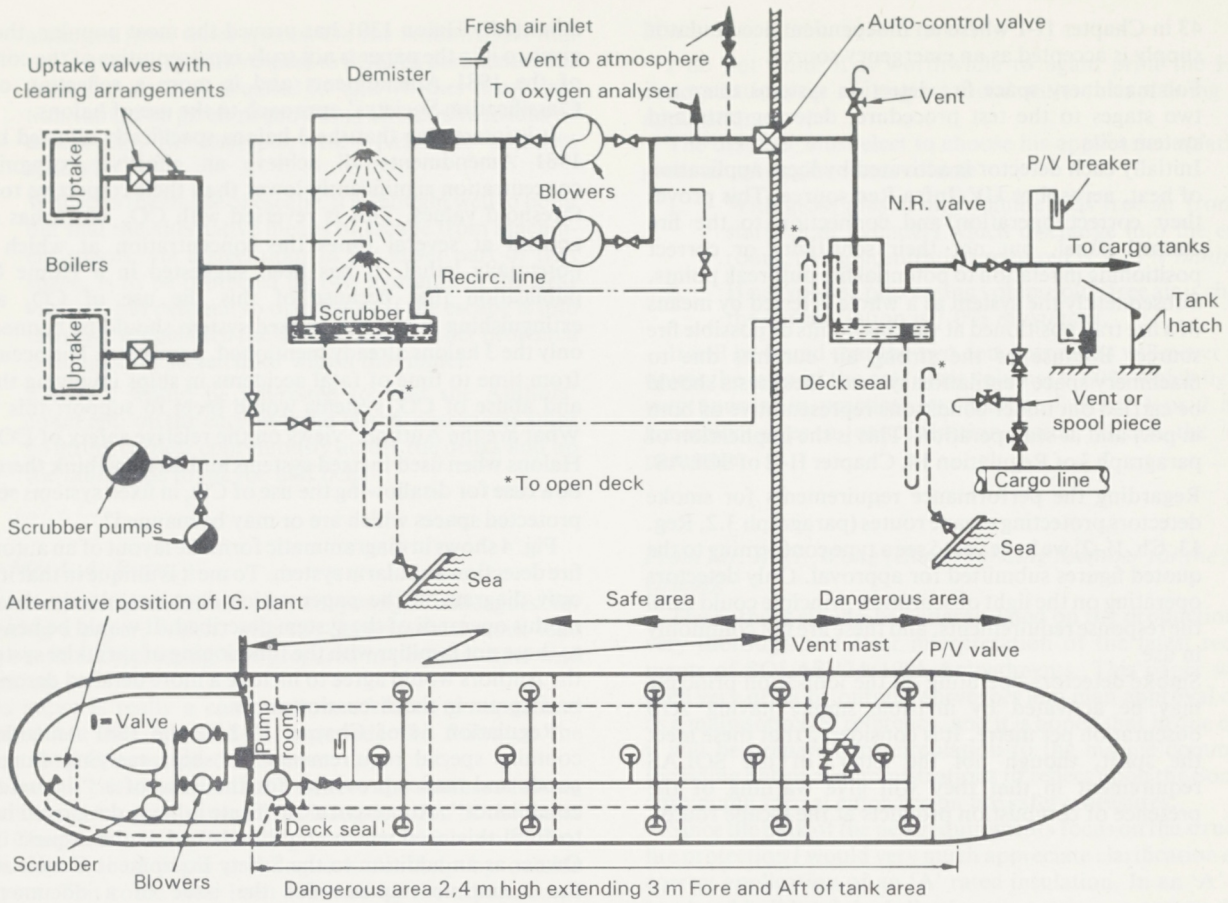


Fig. D.1

of "devices to prevent the passage of flames" referred to half way through paragraph 4.4.12 on page 43. The Authors have mentioned flame screens (of limited use), flame arresters in general and high velocity vents, but included in these items should also be inert gas systems. It is hard to think of an inert gas system as a device and there was much debate on this subject at IMO over the last two years. The eventual outcome, however, was that for a tanker fitted with an inert gas system, the inert gas system could only be considered as a device to prevent the passage of flame provided that flame screens, arresters or high velocity vents were still fitted but that they would require to pass only the flash back test and not the endurance burning test. Recently, at IMO, the further application to Chemical Tankers of both inert gas systems and "devices to prevent the passage of flames" was discussed and the question is not so much that the inert gas systems and flame arresting devices differ from those for oil tankers, but rather to which chemical cargoes they should be applied since many are not flammable. It is only flammable cargoes having a flash point below 60°C that we are concerned with whether they be by definition petroleum products or chemical products. In some cases where flammable cargoes are subject to polymerisation it may even be more dangerous to fit flame arresting devices that to omit them. These applications have not yet been finally approved at IMO so we may yet enjoy our lives without them.

As the Authors state, this subject is outside their expertise. In conclusion may I say "they are not alone".

My thanks to them both for a job well done.

From Mr. A. W. Finney:

By addressing such an extensive subject as the whole fire safety aspects of the 1981 amendments to SOLAS '74, the authors have had to omit some details of a specialist nature.

The Control Engineering department has responsibility for approval of fire detection systems in machinery spaces, and in this context I would make the following comments regarding section 3.10 of the paper:

1. In some respects the Rules exceed the requirements of SOLAS.
   (a) Part 6, Chapter 1, Section 2.8 is applicable where any fire detection system is fitted in a machinery space whether or not the installation is to be operated in an unattended mode.
   (b) No provision is made for a two minute delay before general release of the audible alarm for a machinery space fire. This exceeds the requirement of paragraph 2 of Regulation 14, Chapter II-2 of SOLAS that the alarm should be observed on the navigating bridge and by a responsible engineer officer.
   (c) Since January 1984 it has been a Rule requirement that all fire detectors and manual call points used in machinery spaces be selected from the Society's "List of Type Approved Control and Electrical Equipment". This provides equipment tested to defined environmental severity levels whereas paragraph 3.1 of Regulation 13, Chapter II-2 of SOLAS only states qualitative requirements.

2. The electrical power supply requirements in paragraph 1.3 of Regulation 13 should be read in conjunction with paragraphs 2.3 of Regulation 42, and 2.4 of Regulation

43 in Chapter II-1 where an independent accumulator supply is accepted as an emergency source.

3. For machinery space fire detection systems there are two stages to the test procedure, detector tests and system tests.
Initially each detector is activated by local application of heat, aerosol or UV/Infra Red source. This proves their correct operation and connection to the fire control panel, but not their sensitivity or correct positioning in relation to potential fire outbreak points.
Subsequently the system as a whole is tested by means of a fire tray positioned at various points of possible fire source. Because of the strong air currents due to machinery space ventilation systems these tests should be carried out under conditions representative of both in port and at sea operation. This is the implication of paragraph 3 of Regulation 14, Chapter II-2 of SOLAS.

4. Regarding the performance requirements for smoke detectors protecting escape routes (paragraph 3.2, Reg. 13, Ch. II-2) we have yet to see a type conforming to the quoted figures submitted for approval. Only detectors operating on the light obscuration principle could fulfil the response requirements, and these are not commonly in use.
Smoke detectors operating on the ionisation principle may be activated by invisible smoke having zero obscuration per metre. It is considered that these meet the spirit, though not the letter, of the SOLAS requirement in that they will give warning of the presence of combustion products at the escape routes.

WRITTEN DISCUSSION

From Mr. J. H. C. Robertson:

It is a pleasure to comment on this paper which deals so cogently with the IMO fire safety regulations which have come into force since the presentation of Gordon Coggon's paper to the Technical Association 10 years ago.

In that time the activity of IMO has led to a vast proliferation in fire safety measures applicable to ships. It is to the Authors' credit that they have managed to contend with this avalanche of regulations and end up with such a comprehensive paper which is only marginally larger that its predecessor. This is due in large part to the flow diagrams contained in Figs. 1, 2 and 3. These diagrams must be regarded as forming the heart of the paper.

I believe this paper will become one of the Technical Association's widely consulted, classic reference works which Surveyors and others working in this field will value.

There is an apparent minor inconsistancy in the Historical Note on page 3 which the Authors could perhaps clarify. Reference is made to the improved safety measures for tankers developed in 1975 following the explosions in the "MACTRA", "MARPESSA" and "KONG HAAKON VII". Later on it makes reference to similar improvements made in 1971. If my memory is correct the explosions occurred about the end of 1969 and whilst there may have been improvements made in 1975 it is the earlier fundamental ones which were a direct consequence of the explosions.

In Gordon Coggon's paper cautious mention was made about the introduction of halogenated hydrocarbons or halons as media for fixed fire extinguishing systems which had begun in the early 1970's. Since then one of them in particular, Halon 1301, has gained wide acceptance in marine use to the extent that I would question the authors' statement that CO_2 is still the most popular fixed gas fire extinguishing system, or if it is, that it will long remain so. The 1981 Amendments give equal prominence to the use of Halon 1301, 1211 and 2402 although only Halon 1301 may be stored inside a protected space. Whilst admittedly Halon 1301 has proved the most popular, the bias given to it in the paper is not truly representative of the contents of the 1981 Amendments and is more a reflection of the Classification Societys' approach to the use of halons.

It is interesting that the 3 halons specifically allowed by the 1981 Amendments all achieve an effective extinguishing concentration significantly lower than their respective toxicity threshold values. This is reversed with CO_2 which has to be applied at several times the concentration at which it is potentially lethal. It has been suggested in a Home Office publication that because of this the use of CO_2 as an extinguishing medium in a fixed system should be banned and only the 3 halons already mentioned, permitted. The occurence from time to time of fatal accidents in ships involving the use and abuse of CO_2 systems would seem to support this view. What are the Authors' views on the relative safety of CO_2 and Halons when used in fixed systems and do they think there may be a case for disallowing the use of CO_2 in fixed systems serving protected spaces which are or may be manned?

Fig. 4 shows in diagrammatic form the layout of an automatic fire detection and alarm system. To me it is unique in that it is the only diagram in the paper which does not clearly show the modus operandi of the system described. It would be beneficial to those not familiar with the functioning of sprinkler systems if the Authors would agree to include a more detailed description or diagram in the discussion paper.

Regulation 54 of Chapter II-2 of the 1981 Amendments contains special requirements for ships carrying dangerous goods and makes provision for the issue of a "document of compliance". At present a certificate is being developed in ICD to fulfil this need which could be issued at the request of the Owner as an addition to the Safety Equipment Certificate. In the meantime requests for the issue of a document of compliance should be referred to ICD for instructions.

From Mr. J. V. Rugg:

I would like to take this opportunity to thank the Authors for producing a paper worthy indeed of taking its place alongside those previous illustrious papers born within ICD.

As a member of the Passenger Ship Safety section I have read with interest the parts relevant to my particular discipline and would offer these few points for the Authors' comments:

1. From their text, the Authors are aware of the possible serious injury that may be caused by the slamming of fire doors when released from their hold-backs. Are they also aware of the number of deaths and serious injuries to personnel caused by persons being trapped in watertight doors which, below the bulkhead decks, are accepted as fire doors, when the door, and I use their words, "has been opened just sufficiently for the average person to pass through"? It is understood since 1972 five deaths and four serious injuries have occurred on U.K. passenger ships alone due to persons opening the door "just sufficiently" and becoming trapped. From a fire mechanics aspects it may be unwise, once the opening process has began, to require the door to fully open before closing. In an emergency situation however it is considered some mechanism, such as a leading edge sensor, is required to avoid entrapment, after-all, if a person is injured in a watertight door the integrity of the bulkhead is lost whatever the hazard.

2. As indicated, dead-end corridors for ships carrying more than 36 passengers are restricted to 13 metres and on cargo ships and passenger ships carrying less than 36 passengers to 7 metres. The British Crew Accommodation Regulations restrict the length of blind alleyways to 5 metres, and if passageways of less than that length lead to community spaces, such as recreation rooms etc., then alternative emergency escapes are to be

arranged from those spaces. Do the Authors feel that some rethinking with respect to SOLAS parameters for dead-end corridors is called for and whether consideration should be given to providing alternative means of escape via, for example, crash panels to adjacent spaces?

3. Whilst on the theme of escape, it is thought well to point out that the alternative means of escape from machinery spaces, via a steel door in the lower part of that space, is to be protected by two hydrants in the near vicinity, but external to that space. If the escape is into the shaft tunnel then the door is to be further protected by a light fire screen door within the tunnel.
4. Finally I would be interested to hear the Authors' comments on the current trend in new passengers ships of fitting carpets continuously across the decks and up the bulkheads to maybe half height.

From Mr. J. A. Ross:

I add my congratulations to two younger colleagues for producing a paper, which, with the departmental work load being continually pressing was prepared in personal time with dedication.

This paper is really a compendium of facts, grouped and presented but not intended to supersede the Rules or the International Convention documents.

If I have a criticism it is that I believe the Authors lost an opportunity to pass on some of the interpretation of the Rules Part 6 Chapter 4 and the IMO Requirements which can be vital to the approval of plans and requests for help by outside surveyors. This could have been achieved by the expansion of the Appendix, but, I may be out of order, due to the obvious restrictions on the formating of an already voluminious document. Nevertheless, the point stands.

Mr Holland states that one criticism of the SOLAS documents was that in the case of "foam systems on deck" no concentration of foam ingredients was mentioned. Unfortunately he has repeated the omission in the case of foam concentration for use with Chemicals graded by LR as Medium 'A'. I have not yet met such a product which could qualify for the concentration of 3%. Normally in my experience it has been 6%—I invite comment.

Structural Fire Protection

This subject has always interested the subscriber. This passive protection is very important, painstaking in its application in two dimensions but it has not been stated that the implementation of the process is a two-way protection. I have not known a shipowner to consider that it was his responsibility to fit this protection as a basic duty and it was enforced upon my thinking when in my leisure times in various places, to hear the views of Marine Insurers who were very clear that Shipowners considered the cargo and ship investiment to be of greater importance than sea-going staff. This view is not necessarily always conveyed to Lloyds Register.

Marine Insurance has two faces:

1. The ship, its machinery and capital value being derated as quickly as possible.
2. The cargo, separately insured in almost all cases, nowadays of greater value than the ship and machinery and always increasing in value in an inflationary world.

Hence S.F.P., although presented in the SOLAS documents, has as much to do with protecting the cargo as it has with the ship personnel.

This comment does not, and never has applied to passenger ships where, of course, the fare-paying passengers are the cargo.

Halon Fire Extinguising Systems

I do not think it is worthwhile to again print the Halon concentrations in an engine room without explaining their application.

The designer must elect to choose his application relative to gross or net engine room volume.

1. With gross plus casing volume plus free air from any starting air cylinders which discharge into the engine room, the concentration required is 4.25% *minimum*.
2. If net volume plus casing volume plus free air is chosen, the concentration is 7.0% *maximum*.

It will be found that the two concentrations will never agree unless the ratio of the net/gross volumes is 60% which figure is very unusual in practice, but choice of either 1 or 2 above generally gives a concentration value within the other parameter.

From Mr. B. H. Wong (Corresponding Member for the South Orient):

The authors should be congratulated on the production of a very thorough and clear interpretation of the latest requirements of SOLAS '74/1981 Amendments. This paper will be used very often by outport surveyors and plan approval offices as a main source of reference, and it is hoped that in due course it will be prepared for circulation to the marine community including national administrations to reflect upon the Society's continuing special emphasis on fire safety measures.

Since the bulk of the new requirements focus on the structural fire protection I would very much appreciate clarification on the correct application of an 'A' rated insulation. In an 'A' rated insulated bulkhead the following properties are proven during the one hour fire test.

Stability failure	—	Collapse of elements of structure
Integrity failure	—	cracks occuring in elements
Insulation failure	—	excessive rise of temperature on the unexposed surface.

These findings have to be recorded in the official test report. Every approved insulated 'A' rated bulkhead or deck even though listed and certified would require an illustration on the construction and correct application of the insulation to the bulkhead or deck. This information being a conditional reference in the Society's certificate should be readily available to Builders and Surveyors in order to ensure correct installation.

My question is: where 'A' rated fire insulation is applied to a steel bulkhead the test report should state whether the steel side was exposed to the fire during the test. There is no other indication to state that it is a "general approval" for fire on either side.

If this insulation is to protect spaces from an engine room fire does it mean that the insulation has to be applied on the outside surface of the engine room casing with the internal stiffeners exposed? Isn't it unusual to apply insulation on the outside of the ER casing?

If this insulation is applied inside the casing another illustration would be required to assist Builders on how to attach (spacing and size of steel pins, studs, wire mesh etc.) the insulation to bulkheads and stiffeners or under decks and deck beams as the case may be. Will direct exposure affect the properties of the insulation?

Similarly for fire division penetrations for ventilators and piping which should be the stipulated side for application of the insulation?

My next question is about the Society's stand on the emergency fire pump for cargo ships.

SOLAS '74 had the following requirements for vessels 1000 GRT and above—an alternative means of fire fighting is required if a fire in one compartment can put out of action all the fire pumps.

For vessel 2000 GRT and above—a fixed independent emergency fire pump is required.

SOLAS '74/1981 Amendments state:

For vessels 2000 GRT—a fixed independent emergency fire pump is required.

For vessels less than 2000 GRT—The alternative means of providing *water* for fire fighting is to be to the satisfaction of National Authorities.

L. R. Rules state that

For vessels above 1000 GRT—a fixed independent emergency pump is required. Below 1000 GRT—The alternative means of providing water for fire fighting is to be specially considered.

It is apparent that the Society's Rule requirements for the fixed emergency fire pump is more stringent as far as ship size is concerned i.e. specifying at 1000 GRT and above as against 2000 GRT by SOLAS 1981 Amendments. The question of how much difference this would mean to the Designer/Builder and Owners costs would depend on how one interprets the required arrangements of "alternative means of providing water for fire fighting." Can some examples of this "alternative means" be given in order to evaluate the difference with a fixed independent emergency pumping system that is already clearly described in the Rules?

Next, on the subject of number of fire pumps in cargo ships it is considered that the Rules and Regulations are not easy to interpret.

Pt. 6, 4, Sect. 3.3.2	—	states for cargo vessels above 1000 GRT a min. of 2 independently driven pumps are required. (No mention of emergency fire pump)
Pt. 6, 4, Sect. 3.2.2	—	defines capacity of fire pumps (other than any emergency pump).
Pt. 6, 4, Sect. 3.3.9	—	this Rule requiring "at least one GS/Bilge/Ballast pump in the machinery space to be connected to the firemain" adds to the confusion.

Do the Regulations actually require two designated fire pumps to be located in the main machinery space?

This would mean the necessity for a *third* pump viz. the emergency fire pump.

If the single designated fire pump in the engine room and another fire pump outside (in a separate compartment with separate source of power as stated in the Society's January 1984 Rules Pt. 6, 4, Sect. 12.3.1) make up the total required capacity, will this arrangement not satisfy the requirement of having two independently driven fire pumps for cargo ships 1000 GRT and above?

Fixed Halon Systems

Though the use of approved halogenated hydrocarbon gas systems is considered safe and effective it is thought that certain dangers due to misapplication should be highlighted especially as the new Rules and Regulations allow for automatic initiation (in certain areas under certain conditions)

Can the authors kindly consider detailing the contents of National Fire Protection Assoc. Handbook Sect. 12A-48 Para. A-1-6.1 "Hazards to Personnel" (due to Noise, Turbulence, Cold Temperature and Undecomposed Halon 1301)?

From ICD, Yokohama:

We would like to congratulate the authors for a very interesting and useful paper on the 1981 Amendments to SOLAS 1974.

We feel that some paragraphs of the 1981 Amendments to SOLAS 1974 are too detailed, but this is not consistently the case and there are some contradictions in terms between the Regulations.

We have prepared some queries on the paper and it would be appreciated if the Authors could give us guidance or interpretation on the following items.

1. Para. 3.3.1

   (i) In cargo ships where two fire pumps are located in separate compartments, e.g. one in the engine room and the other in the bulkhead stool in a cargo hold, the space containing the latter fire pump is considered an "other machinery space" and insulated to A-O class standard.

   Is our interpretation correct?

   (ii) The paper states that the space containing the fire pump is considered a *"control station"* for the purpose of determining the fire insulation from Table 8 and Para. 3.4.9, Chapter 4, Part 6 of Notice 2 requires the boundaries of the space containing the fire pump to be insulated to a standard of structural fire protection equivalent to that required for a *control station* in 18.3.2.

   However, Para. 3.3.2.6, Regulation 4, Chapter II-2 of '81 Amendment to SOLAS '74 mentions that the boundaries of the space containing the fire pump shall be insulated to a standard of structural fire protection equivalent to that required for a *control room* in Regulation 44.

   Is there any difference of meaning between *control station* and *control room* in this case?

2. Classification of spaces according to fire risk.

   It is noted that there are some different wordings used for an item in category (1) Control Stations:

   Table 6

   Fire-extinguishing rooms, *fire control and recording stations.*

   Table 7

   Fire-extinguishing rooms, *fire control stations and fire-recording stations.*

   Tables 8 and 10

   Fire-extinguishing rooms, *fire control rooms and fire-recording stations.*

   Is there any difference of meaning in the respective tables?

3. Para 4.1.4

   Fig. D.2 shows a typical arrangement of the front wall of the deckhouse of a tanker.

   Is it acceptable to omit the fire insulation in way of the gutterway?

4. Para. 4.1.11

   (i) Penetrations of 'A' and 'B' class bulkheads for steel ducts of 0.02 m^2 cross-sectional area, or less, are shown in Fig. 13(f).

   Is it acceptable to omit the fire insulation for such steel ducts of small size?

   (ii) In addition to Fig. 13(f), is it acceptable to adopt an alternative as shown in Fig. D.3?

   (iii) Fig. D.4 shows a common arrangement of trunk used as return duct. Is it acceptable without an automatic fire damper fitted to the return duct in the air conditioner room?

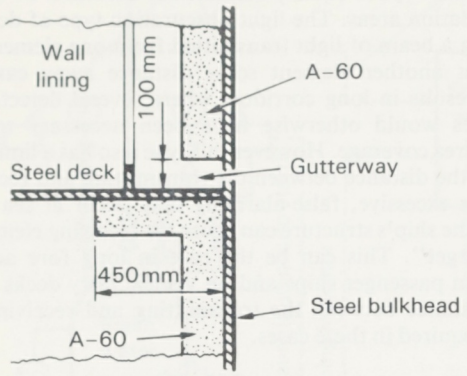


Fig. D.2

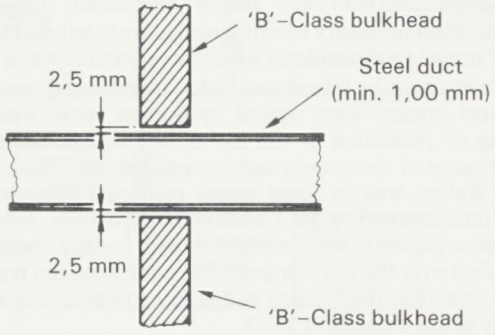


Fig. D.3

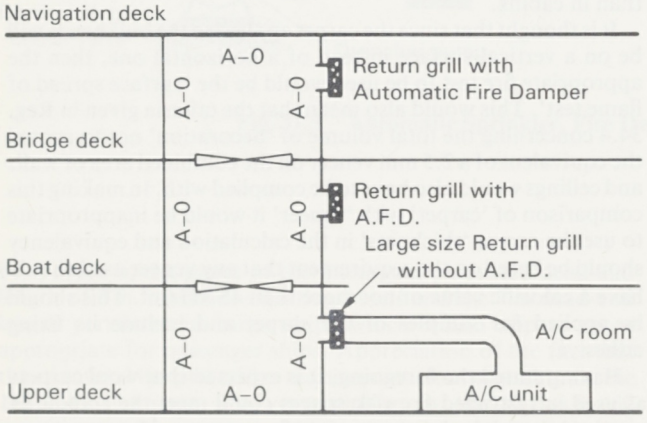


Fig. D.4

5. **Appendix A**

Para. 1

When an electric cable penetration sealing is tested at a horizontal condition as in a deck, is the sealing also acceptable for the vertical condition as in a bulkhead without testing?

6. **Appendix C**

Para. 1

The test pressure of CO_2 line was specified in Para. 6.1.11, Section 6, Chapter 4 of the old Rule as follows:

"For systems using carbon dioxide, the distribution manifolds and the pipes between the storage cylinders and the distribution valve are to be guaranteed by the manufacturers to have been satisfactorily hydraulically tested to a pressure of at least *122* bar (124 kgf/cm^2). The manufacturers are to guarantee that at least 10 per cent of the pipes from the distribution valve to the discharge nozzles have been satisfactorily hydraulically tested to a pressure of at least *10* bar (10 kgf/cm^2). On completion of the installation the joints are to be tested pneumatically to a pressure of at least *7* bar (7 kgf/cm^2) with the discharge openings closed."

The paragraph has been removed from Notice No. 2 and the recommended pressure is introduced in the paper with different figures as follows:

"The distribution manifolds and the pipes leading from the cylinders to the distribution manifolds must be guaranteed by the makers or suppliers to have been satisfactorily tested to a pressure of at least *125* bars. The makers or suppliers must guarantee that not less than 10 per cent of the pipes from the distribution manifolds to the spaces being protected have been satisfactorily tested to a hydraulic pressure of at least *125* bars. In cases where the national authority of the country of registry of the ship has other standards for the quality and testing of the piping, these will generally be accepted."

"After installation test all joints with either CO_2 gas, compressed air, or for a halon system with freon, to a pressure of about *6* bars with the discharge opening closed.

It is considered that as the test pressure is a very important item to the manufacturers, it should be included in the Rule as before.

AUTHORS' REPLY

The Authors wish to thank all colleagues for the interest shown in the paper and particularly to those who made contributions to this discussion. The paper has been greatly enhanced by their comments.

To Mr. Coggon:

We entirely agree the majority of shipboard fires occur in the engine room but, as is the case with many so called "statistics", the actual figures may be somewhat misleading. While a figure of 60% is reasonably accurate many engine room fires actually occur during repairs when the vessel is lying alongside. Nevertheless it is widely recognised that engine room fires are a major hazard and the International Association of Classification Societies (IACS) have recently discussed this problem at some length. Among the many areas of concern identified for

particular attention are measures to prevent spillage of oils and other flammable liquids, the distribution of piping conveying flammable liquids, the flashpoint of oil fuel, thermal oil installations and the segregation of high risk components. Proposals to improve the standards of fire prevention in engine rooms concerning these aspects have been submitted to IMO for consideration.

With regard to further development of regulations, IMO has recently issued the 1983 Amendments to the International Convention for the Safety of Life at Sea 1974, Volume II addressing the International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk and Volume III the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk. Both Codes enter into force on 1st July 1986.

To Mr. McCulloch and Mr. Woodcraft:

Feed-back of the practical experience of Surveyors in the field is an essential part of the Society's ongoing work concerning regulation development and their comments have been welcome.

The complexity of fire extinguishing systems fitted on some of todays ships is such that the design, supply and installation of the equipment is usually sub-contracted by the Builder to a suitably qualified fire engineering company. Thus it follows that maintenance and servicing should similarly be carried out by the manufacturer or accredited agents. However, there are no moves being made at IMO to address this aspect and it is the authors' opinion that the classification societies may find it necessary to consider requirements for Maintenance and Service Manuals which list parts to be examined/tested and the regularity with which such work should be carried out. Requirements already exist within the SOLAS Regulations and the Rules for all fire safety equipment to be in full working order and readily available. This latter point should be kept in mind at all surveys and deficiencies corrected.

Regrettably one of the important matters raised concerns an aspect of fire safety over which the Society cannot exercise any control, crew training. This has already been referred to in the paper and Mr Woodcraft has confirmed that the lives of many seamen are at risk by their lack of knowledge of their own ship's fire extinguishing equipment.

To Mr. Oxford:

The clarification given by Mr Oxford of the amendments to the inert gas system which have occurred since writing the paper are much appreciated.

The authors endorse Mr Coggon's request that a paper dedicated to cargo tank venting and inert gas systems be written and look forward to its possible presentation in the next session.

To Mr. Finney:

Mr Finney's contribution concerning the electrical and control engineering aspects of the SOLAS Regulations is greatly appreciated. It is agreed that only fire detectors operating on the light obscuration principle can fulfil the response requirements of the regulations and also agreed that these are not yet in very common use although the Society has 'type approved' such detectors.

Smoke detectors operating on the ionisation principle have been accepted as equivalent by the Society when acting on behalf of several administrations as also have smoke detectors operating on the optical light scatter principle. However, both of these detector types have limitations. The "dirty" smoke which can be expected from many of the materials found in free-standing furniture items on todays ships can, under certain circumstances, coagulate to such a particle size that it will not pass through the wire mesh of the detector head of the ionisation type, thus the light obscuration type of detector would be better suited for use in accommodation areas. False-alarming of the optical light scatter type of detector can result from the presence of airborne dust or ingress of insects, otherwise this type is equally suitable for detection of fires in accommodation areas. The light obscuration type of detector comprising a beam of light transmitted from one element and received at another element some distance away can give excellent results in long corridors where several detectors of other types would otherwise have been necessary to give adequate area coverage. However this type also has a limitation in that, if the distance between the transmitting and receiving elements is excessive, false-alarming may occur at sea when flexing of the ship's structure can cause the receiving element to be "off-target". This can be the case in long fore and aft corridors in passenger ships and on vehicle ferry decks and a shorter distance between the transmitting and receiving elements is required in these cases.

To Mr. Robertson:

There is clearly nothing wrong with Mr Robertson's memory. The explosions in the supertankers referred to did occur about the end of 1969. The improved safety standards for tankers were developed in 1971 following these horrific incidents but implementation of the new requirements by IMO were not recommended for adoption until the end of 1973. The clarification sought by Mr Robertson is appreciated and enables us to correct an obvious error.

As Mr Robertson has clearly elucidated, Co_2 at the concentration necessary to extinguish a fire is lethal. However, most if not all fatal accidents which have occured when Co_2 has been inadvertently introduced into an enclosed space with personnel present were caused by human error, inadequate training of personnel in the use of the equipment or poor maintenance of the system and its components. The extensive use of halons was to some extent restricted because of the limitations imposed by the Amendments. However, subsequent experience gained in service together with further research into their effect over the last few years has convinced the regulatory bodies to extend their use to additional spaces and this is now actively being pursued by IMO.

In accordance with Mr Robertson's request figure 4 has been modified to include the modus operandi for each of the water systems and is shown in Fig. D.5.

To Mr. Rugg:

It is concluded that the trend of fitting carpet continuously across the deck and up the bulkheads to about half-height is more of note where fitted in corridors forming escape routes than in cabins.

It is thought that since the carpet applied to the bulkheads will be on a vertical surface instead of a horizontal one, then the appropriate fire test to be used would be the 'surface spread of flame test'. This would also mean that the criteria given in Reg. 34.4 concerning the total volume of 'decoration' not to exceed the equivalent of a 2.5 mm veneer on the combined area of walls and ceilings would also have to be complied with. In making this comparison of 'carpet' with 'veneer' it would be inappropriate to use the carpet 'thickness' in the calculation and equivalency should be based on the requirement that any veneer used should have a calorific value of not more than 45 MJ/m^2. This should be applied for samples of the carpet and include its fixing adhesive.

Having stated the foregoing, it is expected that wool carpets as used in restricted fire risk spaces could meet the standards required, but only the appropriate fire tests would prove it.

The clarification concerning escape routes at low levels in the machinery spaces of passenger ships is agreed and appreciated. With regard to dead-end escape routes, the authors share Mr Rugg's misgivings about the 13 m length permissible in passenger ships carrying more than 36 persons. Reference has

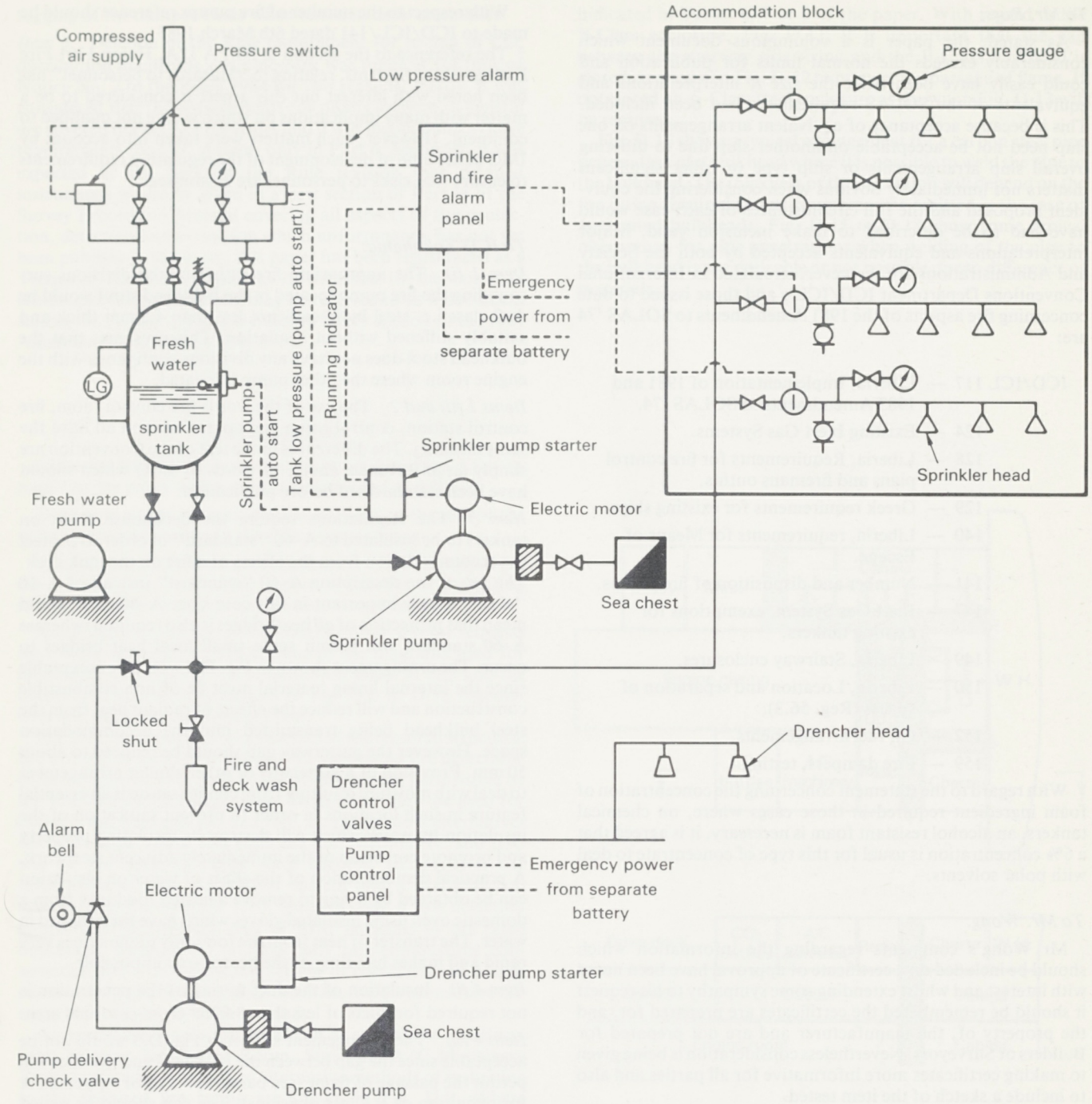


Fig. D.5 Automatic Sprinkler, Fire Detection, Fire Alarm and water Spray System

been made in the paper to the maximum permitted dead-end length of 5 m in offshore floating hotels and the 7 m dead-end length permitted in cargo ships which would appear more appropriate for passenger ships. Appreciation of the fact that the structural fire protection requirements for cargo ships in the 1981 Amendments are very similar to the SOLAS '60 requirements for passenger ships, gives rise to the conclusion that it does not seem justified to permit a dead-end length of 13 m in passenger ships. The authors agree that revision of this clause is long overdue.

With regard to sliding watertight doors below the bulkhead deck and their closing arrangements, it is agreed that anything which prevents the door fully closing will destroy the integrity of the bulkhead from both fire and watertightness aspects. A similar problem arises with galley rolling shutters where plates of food can be displayed on the surface on which the shutter is to descend, thus preventing full closure. The answer in these cases is to provide a ridge or similar upstand such that nothing can be placed directly under the shutter. With sliding watertight doors the type of foreign 'body' likely to be trapped is very different and perhaps the leading edge sensor suggested would be a suitable fitment. However, care should be taken concerning the arrangements made for reserves of power to close the door to ensure that satisfactory closing, after being stopped, can be achieved.

To Mr. Ross:

As stated, the paper is a voluminous document which considerably exceeds the normal limits for publication and could easily have been twice the size if interpretations and equivalents of the SOLAS requirements had been included. This is because acceptance of equivalent arrangements on one ship need not be acceptable on another ship due to differing overall ship arrangements or ship type or other significant matters not immediately obvious when considering the equivalent proposed and the full circumstances of each case would have had to be described to make inclusion valid. Major interpretations and equivalents accepted by both the Society and Administrations are, however, circulated in International Conventions Department ICD/ICL's and those issued to date concerning fire aspects of the 1981 Amendments to SOLAS '74 are:

ICD/ICL 117 — Liberia, Implementation of 1981 and 1983 Amendments to SOLAS '74.

124 — Existing Inert Gas Systems.

128 — Liberia, Requirements for fire control plans and firemans outfits.

129 — Greek requirements for existing ships.

140 — Liberia, requirements for Means of Escape.

141 — Number and disposition of fire pumps.

147 — Inert Gas System, exemptions for existing tankers.

149 — Liberia, Stairway enclosures.

150 — Liberia, Location and separation of spaces (Reg. 56.3).

152 — Oil fuel arrangements.

159 — Fire dampers, testing.

With regard to the statement concerning the concentration of foam ingredient required in those cases where, on chemical tankers, an alcohol resistant foam is necessary, it is agreed that a 6% concentration is usual for this type of concentrate to deal with polar solvents.

To Mr. Wong:

Mr Wong's comments regarding the information which should be included on a certificate of approval have been noted with interest and whilst extending some sympathy to his request it should be remembered the certificates are prepared for, and the property of, the manufacturer and are not prepared for Builders or Surveyors. Nevertheless consideration is being given to making certificates more informative for all parties and also to include a sketch of the item tested.

The Society's Certificates of Approval issued for 'H' or 'A' Class bulkheads are, unless otherwise stated, approved for fire from either side of the division i.e. the steel side is presented to the furnace during the appropriate test since this is the most onerous case. When a test has been carried out with the insulation side exposed to the fire, this is stated on the certificate together with the comment "Restricted application". Thus it would not be compulsory to apply insulation to the outside of the engine room casing; the choice is the responsibility of the designer. Materials which have been certified for use in an insulated division, unless specifically designed to react when directly impinged by flame, will be largely unaffected by direct exposure to fire within the material's certified insulation time.

To prevent heat tracking along penetrations the insulation should be applied to the penetration on the insulated side of the division.

IACS agreed some years ago that an emergency fire pump would be required on vessels 1000 GRT and above and not 2000 GRT and above as required by SOLAS.

With respect to the number of fire pumps reference should be made to ICD/ICL/141 dated 6th March 1985.

The reference to the section in NFPA 12A, Halon 1301 Fire Extinguishing Systems, relating to "Hazards to personnel" has been noted with interest but this aspect is considered to be a matter with many implications on which we are not qualified to comment. However, such matters were taken into account by IMO at the time of development of the regulation requirements to ensure that risks to personnel are minimised.

To ICD Yokohama:

Item 1 (i) The appropriate fire rating of the divisions surrounding the fire pump located in the bulkhead stool would be A-0 class i.e. steel bulkheads not less than 4.5 mm thick and suitably stiffened without insulation. This presumes that the bulkhead stool does not have any divisions contiguous with the engine room where the other pump is located.

Items 1 (ii) and 2 The use of the words fire control room, fire control station, control room and control station all have the same meaning. The differences in the text of the Convention are simply an unfortunate choice of words by IMO which should have been standardised before publication.

Item 3 The Regulations require the deckhouse front on tankers to be insulated to A-60 "standard" in order to protect the accommodation from the effects of a fire on the tank deck. The use of the description A-60 "standard" instead of A-60 "class" is very important in this case since A-60 class would mean that protection of *all* heatbridges is also required, whereas A-60 standard will permit some small local heat bridges to occur. The arrangement shown in Fig. D.2 would be acceptable since the internal lining material must be of non-combustible construction and will reduce the effects of radiant heat from the steel bulkhead being transmitted into the accommodation space. However the gutterway gap should be reduced to about 50 mm. Provision of a gutterway or other similar arrangement to deal with moisture resulting from condensation is an essential feature in such locations in order to prevent saturation of the insulation by water which will destroy its insulating property and promote corrosion of the immediately adjacent steelwork. A practical demonstration of the effect of water on insulation can be obtained by trying to remove a heated food tray from a domestic oven using insulated gloves which have been dipped in water. The transfer of heat from the food tray to the skin is very rapid and makes handling of the heated tray impossible.

Item 4 (i) Insulation of the duct in way of the penetration is not required for ducts of less than $0.02m^2$ cross-sectional area.

Item 4 (ii) The arrangement shown in Fig. D.3 would not be acceptable since the gap between the bulkhead and the duct will permit the passage of flame (see paragraph 5 (i) of Appendix A for definition of B Class divisions). The gap should be sealed with a non-combustible compound or fitted with a tight collar as shown in Fig. 13(f). The collar may be of thin gauge steel if preferred by the Builder. The prime requisite is that it should be a tight fit.

Item 4 (iii) The arrangements shown in Fig. D.4 are acceptable.

Item 5 Fire testing of penetration components should be carried out in such a way as to demonstrate that the integrity of any division in which they are used will not be impaired. Generally this will mean that penetration components tested on deck assemblies in a horizontal plane should be acceptable for use as bulkhead penetrations without further test since the effects of the test fire will be more severe in the horizontal test. This obviously means that components tested in the vertical plane may not be acceptable for use in the horizontal plane without further test. This is particularly the case with some types of fire damper which have been found satisfactory when tested in bulkheads but have had an integrity failure due to

sagging of the damper blade when tested in deck assemblies.

Item 6 Deletion of the Rule requirement for testing of CO_2 distribution manifolds and pipework was made at the time of Notice No. 2 to the Rules 1984 for two reasons. Firstly, it was considered that the requirements for piping systems in general are covered in Part 5 of the Rules and it was inconsistent to have requirements for CO_2 systems only in Part 6. Secondly, it was expected at the time of the Rule revision that detailed instructions would be given in a new section of Part H of the Survey Procedures Manual covering all aspects of fire protection, detection and extinction which unfortunately has not yet been published. However, this paper has been reproduced as a Technical Reprint for general distribution to the Society's clients and in the meantime may be referred to as a document stating the Society's policy on the fire safety aspects of the 1981 Amendments to SOLAS '74.

CORRIGENDA

Attention has been drawn to an incorrect definition given on page 4 of the paper which should be amended as follows:

Delete the words 'or ignition temperature' at the end of the second paragraph and add the following sentence:

The fire point is the lowest temperature at which the heat from the combustion of a burning vapour is capable of producing sufficient vapour to enable combustion to continue.

In addition to the foregoing contributions several requests have been received to publish some of the diagrams used for illustration purposes at the presentation made in HQ and the outports. These are reproduced in Fig. D.6 to D.18 together with any necessary explanatory text.

Fig. D.6, D.7, and D.8 are examples of the required structural fire protection arrangements and the associated fire detection/extinction systems for each of the three methods permissible by the Regulations for cargo ships. Method IC must be used for tankers, but Methods IIC and IIIC are permissible alternatives for other cargo ships. It is expected that Methods IC and IIIC will be the most favoured since Method IIC requires the installation of both a sprinkler system and a fire detection system, whereas Method IIIC requires only a fire detection system and limited floor area of 50 m^2 enclosed by fire rated bulkheads. Method IC requires only non-combustible construction and a fire detection system in corridors and escape routes. It should be noted that the main fire divisions have the same fire rating in all three methods.

An interesting insulation detail can be seen at the cruciform joint between the Engine Room, Stairway, A/C Machinery Room and Radio Room. The alternative methods of insluating to the required fire rating are shown in Fig. D.9. Where insulation of the E. R. Casing is applied to the E. R. side of the bulkheads, arrangement (a), no heat bridges exist to transmit the effects of a fire in the E. R. to any other space. However a heat bridge exists between the A/C Machinery Room and the Radio Room which must be protected to A-15 Class as shown for a distance of 450 mm along the bulkhead heat bridge. In arrangement (b) the insulation of the E. R. Casing is applied to the accommodation side of the bulkheads thus giving rise to heat bridges to each of the other three spaces which must be protected to A-60 Class for a distance of 450 mm on each face of the cruciform bulkheads.

Fig. D.10 to D.13 show some typical arrangements for the protection of stairway enclosures by A-Class or B-Class bulkheads depending on whether more than two decks are connected (A-Class enclosure) or only two decks are connected (B-Class enclosure). The figures illustrate the different circumstances where A or B Class is required and it should be remembered that insulation may be required on some sides of the enclosure, depending on the nature of adjacent spaces, as indicated in Tables 6, 7 or 8 of the paper. With regard to the B-Class enclosure, Fig. D.11, it is important that the gap between the stairway side-string and the B-Class bulkhead is closed, as shown in Fig. D.12 to prevent the passage of flame. If not closed an A-Class steel enclosure as shown in Fig. D.13 will be required.

Fig. D.14 shows a typical arrangement for a carbon steel pipe penetration of a bulkhead where it is possible to weld the pipe to the bulkhead. The thickness of the insulation will depend on the fire rating required and of course may be omitted in the case of A-0 rated bulkheads. Fig. D.15 to D.18 show some typical alternatives for pipe penetrations when welding of the pipe to the bulkhead is not desirable or not possible due to difference of materials.

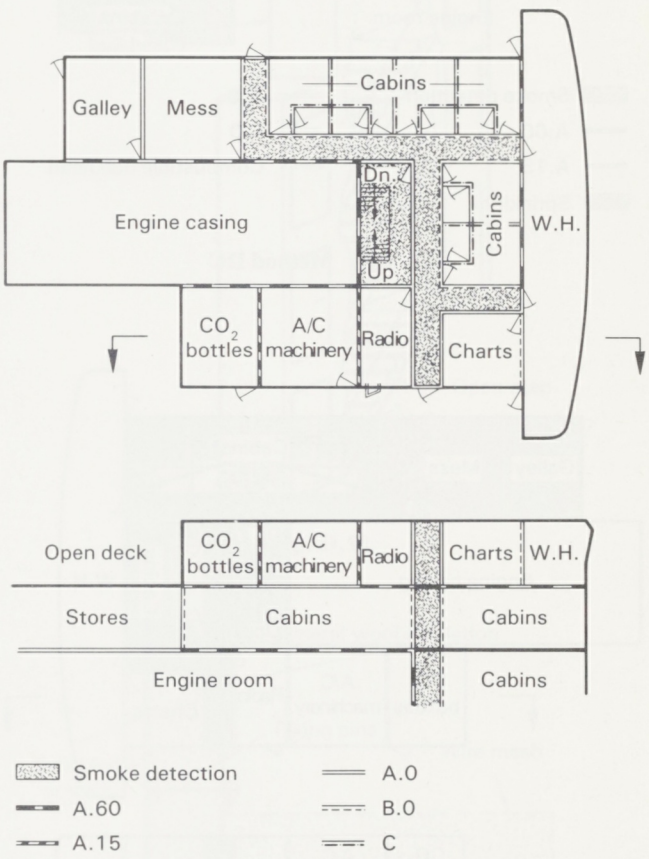
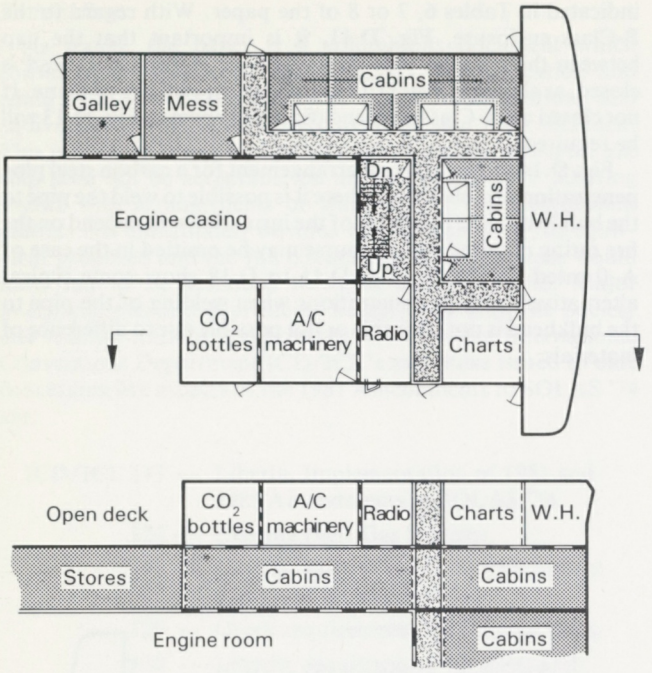
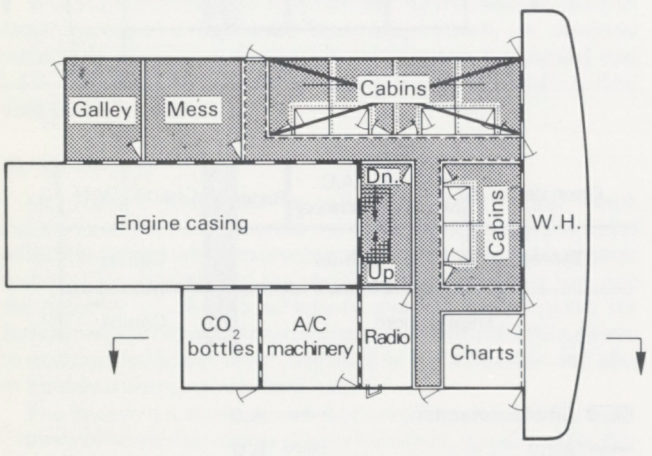


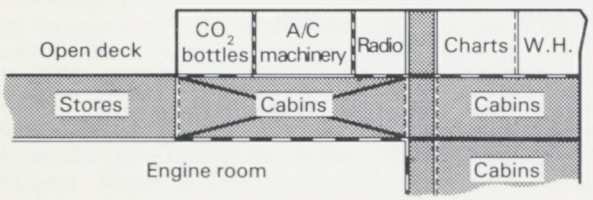
Fig. D.6 Method IC



Smoke detection — A.0
A.60 — B.0
A.15 — Combustible bulkhead
Sprinklers

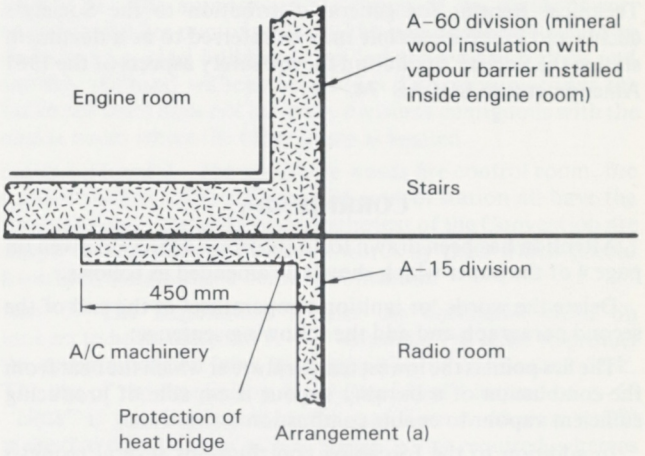
Fig. D.7 Method IIC





Fire detection system — A.0
A.60 — B.0
A.15 — Combustible bulkhead
Not to exceed 50 m^2 floor area

Fig. D.8 Method IIIC



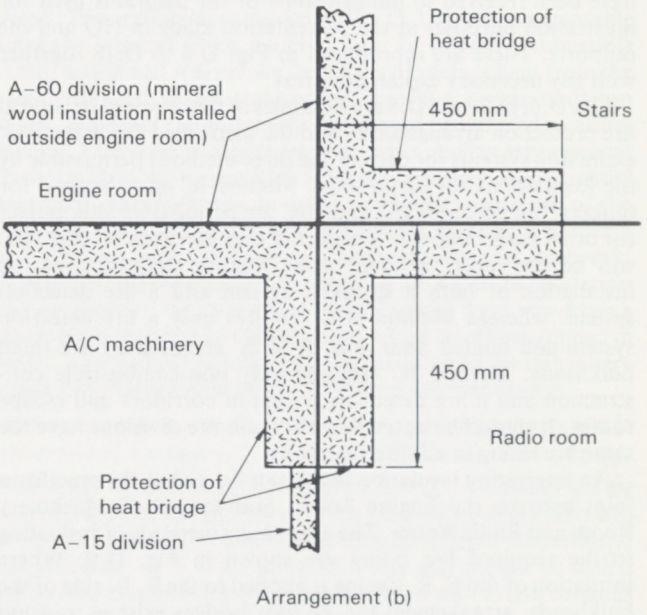


Fig. D.9

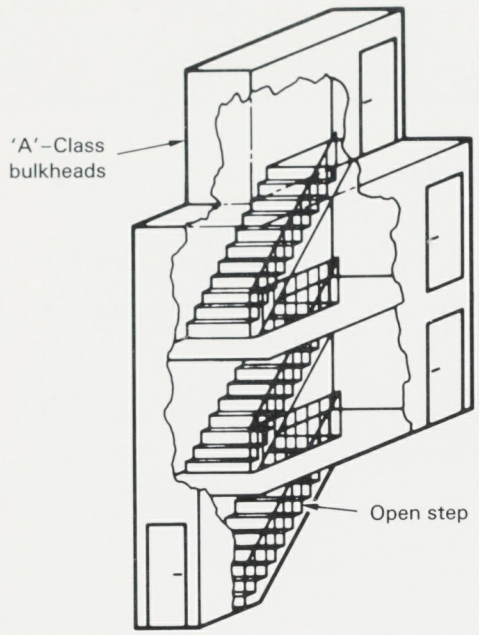


Fig. D.10

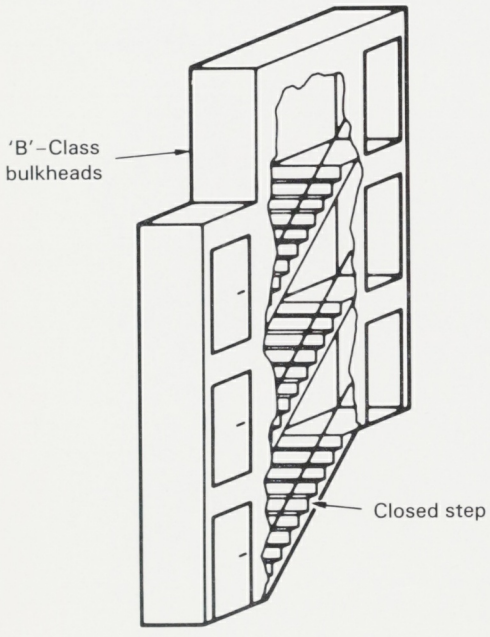


Fig. D.11

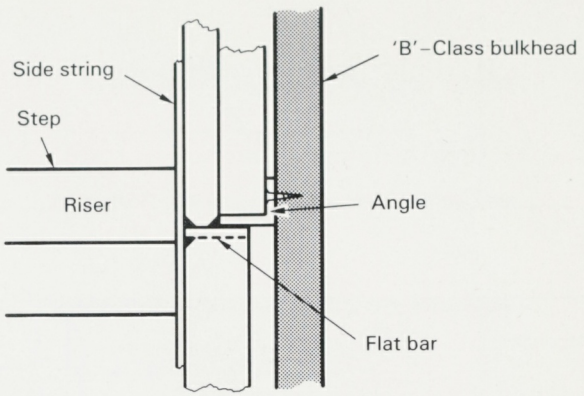


Fig. D.12

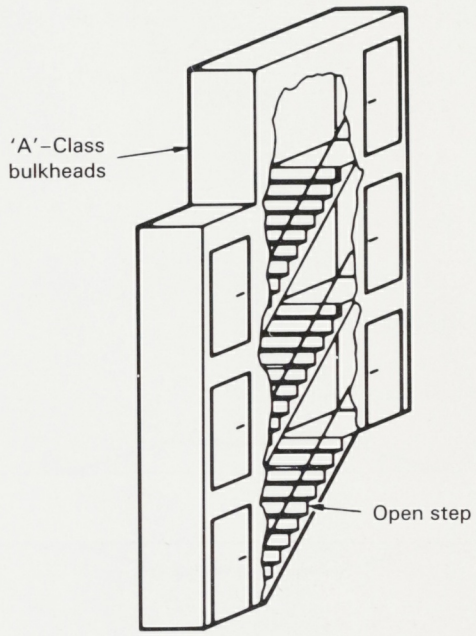


Fig. D.13

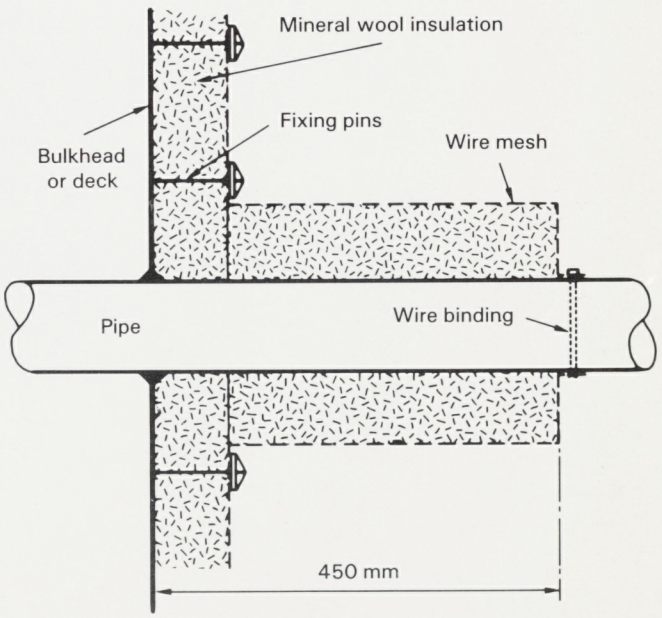


Fig. D.14

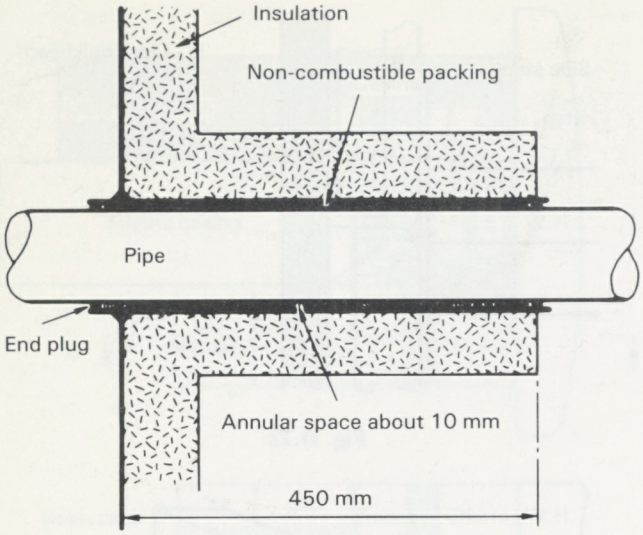


Fig. D.15

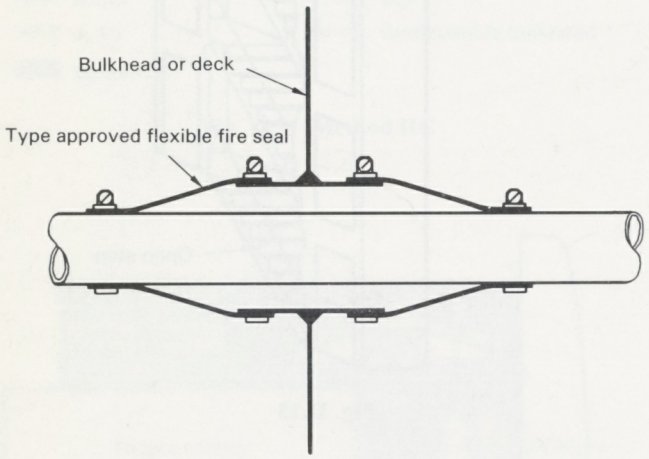


Fig. D.16

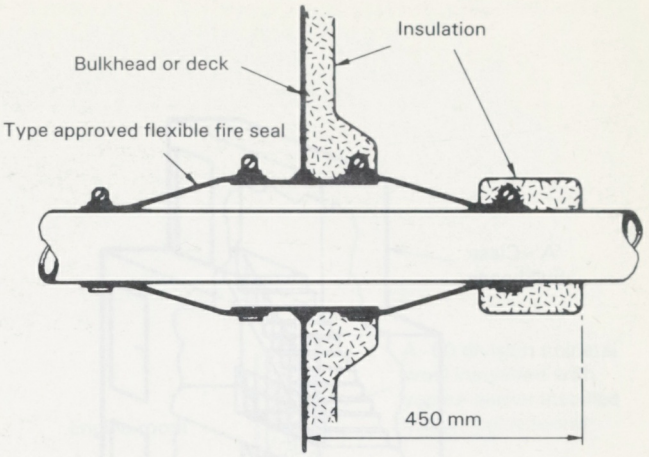


Fig. D.17

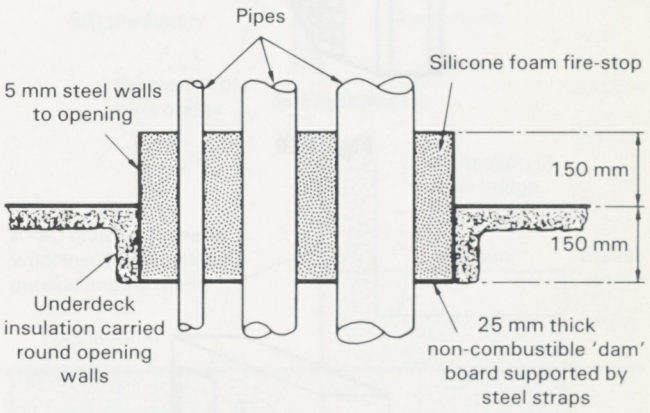


Fig. D.18

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Lloyd's Register Technical Association

MICROPROCESSORS ON SHIPS

A. W. Finney

Paper No. 6. Session 1984-85

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Written contributions to the discussion of this paper are invited from members of the Lloyd's Register Technical Association. To ensure inclusion in the discussion paper, the contributions should be received by the Hon. Secretary in London not later than the 19th July 1985.

Hon. Sec. J. S. Carlton
71 Fenchurch Street, London, EC3M 4BS

MICROPROCESSORS ON SHIPS

by

A. W. Finney

SYNOPSIS

Equipment incorporating microprocessors is increasingly to be found aboard ships. This paper reviews the operation of shipborne microprocessors in machinery control, alarm, data acquisition and diagnostic systems. The attendant changes in production and testing techniques are discussed together with their implications for surveyors.

Details are given of the additional hardware essential to the operation of microprocessors and the means of software generation are indicated.

The salient features of digital systems are discussed including the advantages of signal multiplexing and distributed systems. Hardware reliability and methods of enhancing system integrity are reviewed.

A glossary of technical terms is included.

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1. INTRODUCTION

The use of automatic and remote controls in ships has increased steadily since the early 1960s, as has their sophistication. Recognising the important role control engineering would play in classification the Society published the first Guidance Notes for Surveyors in 1963. In the 1968-69 session of the Lloyd's Register Technical Association, A. R. Hinson presented a paper entitled 'First Steps in Control Engineering Made Easy', the purpose of which was to familiarise surveyors with the fundamental principles of the technology. While the principles remain unaltered, the means of their achievement have changed out of all recognition. The technology described in that paper is now rapidly becoming obsolete and surveyors need to become aware of the fundamentals of the 'New Technology' as it relates to control engineering.

While the 'Microprocessor Revolution' has been with us for a number of years its impact is only now being felt in the marine engineering industry. As momentum gathers, surveyors will be called upon more and more frequently to survey and examine microprocessor based digital control systems. It will not be sufficient to take a simplistic 'black-box' approach to these systems and accordingly it is felt appropriate at this time to present information to give surveyors an insight into the fundamentals of digital systems and their terminology, an appreciation of the advantages and disadvantages of their use and an awareness of the significant installation features to be examined during survey.

2. MICROPROCESSOR TECHNOLOGY

2.1 Fundamental Operations

A microprocessor is an information handling system. It can move, process and store information. These operations are not unique to microprocessors since they have been carried out over the years by mechanical, hydraulic, pneumatic and electrical systems as can be illustrated by examples with which many surveyors will be familiar.

Moving Information:

Much information regarding machinery status is brought to a console in the machinery control room for display. One such item, the position of the main engine turning gear is shown in Fig. 1.

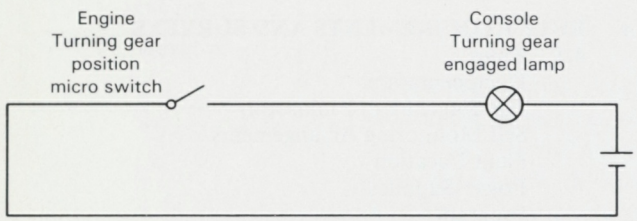


Fig. 1 Information Transfer

Processing Information:

A microprocessor carries out both logical and arithmetic operations. As an example of a logical OR function consider the simple shuttle valve found in most pneumatic control systems and shown in Fig. 2. A pressure signal will be available at the output port C if there is pressure at either input A or input B. Fig. 2 illustrates the case when there is pressure at A and not B.

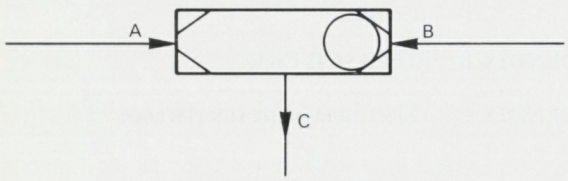


Fig. 2 Pneumatic Shuttle Valve

An example of an arithmetic operation can be seen in the electrohydraulic follow-up steering gear shown in Fig. 3. The mechanical linkage subtracts the rudder stock position information from the demanded position signal set by the telemotor and the difference controls the output of the variable delivery pump which turns the rudder to reduce the difference signal to zero.

Storing Information:

The contactor circuit for an electric motor (Fig. 4) affords an example of information storage which is very frequently encountered.

The contactor coil is energised when the start button is pressed and remains energised via a pair of its own contacts after the start button has been released. The circuit thus 'remembers' the instruction to start the motor after it has been removed. Similarly, when the stop button is pressed the contactor is de-energised and remains so after that button is released.

An interruption in the power supply will cause the circuit to loose the stored information that the motor is to run. This is a factor which is also relevant when considering the memory function of microprocessor systems.

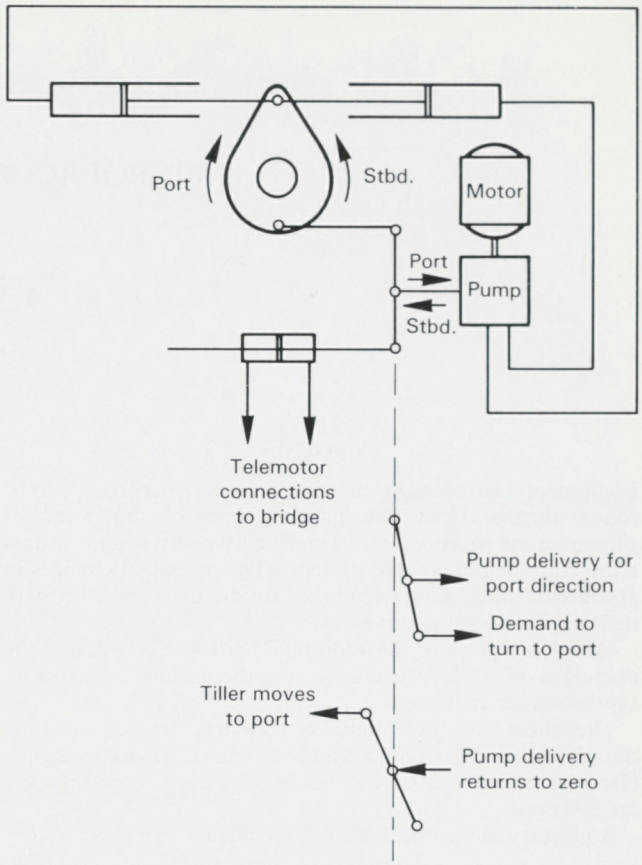


Fig. 3 Steering Gear

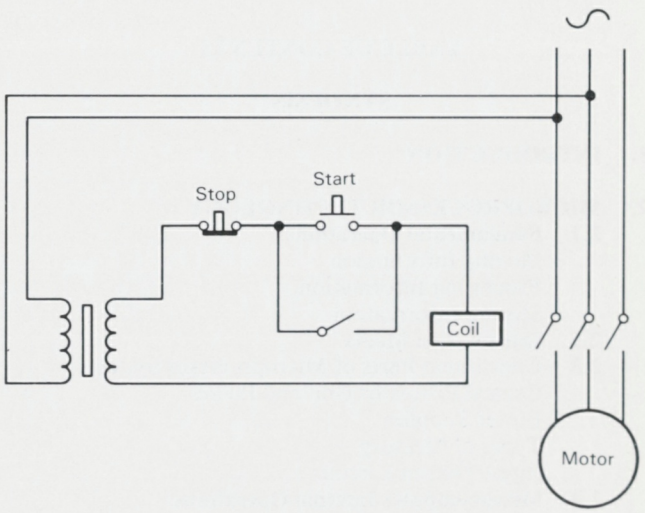


Fig. 4 Motor Contactor Circuit

2.2 Information Media

The oldest methods by which information has been transferred and stored are speech and writing, which involve a large variety of complex sounds and symbols. The simplest possible system for representing information is based on only two states or conditions and is referred to as a *binary* system. The two states are termed *logic levels* and assigned the notations zero and one.

Microprocessors operate on information in binary form, logic level one being identified with a voltage near to the supply

voltage of 5,0V, and logic level zero with approximately zero volts.

Binary arithmetic and logical operations are discussed in Appendix A together with simplified circuits for their execution. For an appreciation of the working of microprocessor systems, however, it is sufficient to note that binary numbers are made up of digits which may only be zero or one and that the value of a one in each successive digit position increases in powers of two. A binary digit is referred to as a *bit*, and an 8-bit number is known as a *byte*.

Binary numbers being processed within computers are also referred to as *words*. However, in order to deal with real words in any computer a binary number is allocated to each letter of the alphabet, upper and lower case, and the punctuation marks. One of these codes, the American National Standard Code for Information Interchange (ASCII) is given in Appendix B.

2.3 Constitiuent Parts of Microprocessor Systems

The term microprocessor is often erroneously used to refer to the whole of a microprocessor based system. Fig. 5 shows all the essential components of such a system. The solid-line blocks indicate hardware, usually produced as separate units, although single-chip microcomputers are available. Equally essential to the operation of the system is the list of instructions, the program. To distinguish this from the physical hardware the program is referred to as *software*.

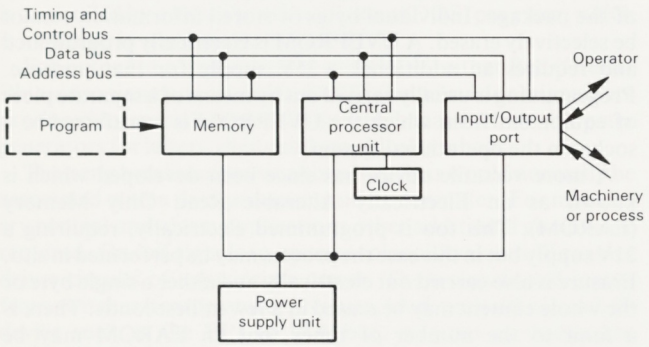


Fig. 5 The Essential Constituents of any Computer Control System

Central Processor Unit and Busses:

The microprocessor as such corresponds with the central processor unit (CPU) shown in Fig. 5. Some chips also include the system timing clock circuit. The operations performed by the CPU may be arithmetic, or logical functions. To carry out these operations the CPU includes a limited amount of memory for working registers and sufficient built-in program to enable it to interpret the instructions of the system program. The transfer of information within the system to and from the memory and the interface units is all under the control of the CPU. The precise timing of these operations is controlled by pulses derived from the clock circuit which is usually a crystal controlled oscillator operating in the frequency range 1-20 MHz.

The path by which information enters and leaves the CPU is the *data bus*. This consists of a group of conductors connecting all the active components of the system. For an 8-bit microprocessor system there are eight conductors forming the data bus. In control applications 8-bit systems are still the norm and unless otherwise stated these are the systems referred to in this paper, but 16- and even 32-bit systems are becoming available mainly for scientific and business data processing applications. In a 16-bit micro computer the data bus may have 16 conductors or it may have only 8, the data being transferred as two bytes in succession.

In order that program instructions may be accessed and data stored in and retrieved from memory every location in the memory, where a single byte of data may be stored, must have a unique address. For 8-bit systems there are usually 65,536 addresses which is 2^{16} and hence requires a 16-bit binary number to define each address. In computer terms there are 64K addresses, 1K being 2^{10}, i.e. 1024. The *address bus* is a group of 16 conductors connecting all the active components of the system. Where systems require more then 64K of memory to be addressed additional conductors are required or two successive signals may be passed along the address bus.

The operation of the *timing and control bus* is best illustrated by consideration of the process by which the CPU *writes* information into memory and *reads* information or program from memory.

To write, the CPU performs the following operations:

(i) It selects the memory register which is to receive the data and connects its address signal to the address bus.

(ii) It puts the byte of data that is to be transferred onto the data bus.

(iii) It sends a signal via the control bus to indicate that a write operation is to be carried out.

(iv) After a delay period sufficient to allow the memory address decoding circuit to function, the CPU sends a signal via the timing bus to cause the data to be stored at the selected address.

In order to read from memory the CPU controls the following sequence of events:

(i) It selects the memory register from which it requires data and connects the appropriate address signal to the address bus.

(ii) It sends a signal via the control bus to indicate that a read operation is to be carried out. This causes the memory to connect the output of the selected register to the data bus.

(iii) After a delay period sufficient to allow for signal propogation along the data bus the CPU admits the information on the data bus to the appropriate internal register.

Power Supplies:

Earlier microprocessor systems required more than one voltage level from their power supply units. The major current requirement was from a + 5,0V d.c. supply but + 12V and − 5V supplies of lower current capability were also necessary. In order to avoid damage to the circuits, the supplies had to energise in a prescribed sequence at system power up and decay in the correct order when switched off. Present systems incorporate circuits on each chip to derive any necessary secondary supply voltage from the + 5,0V supply.

The quality of the power supply unit for a microprocessor system needs to be better than would be required for a system employing electro-magnetic relays. The 5,0V output must be held within ± 10% regardless of the mains input voltage and frequency excursions which necessitate special stabilisation of power supplies for shipboard applications.

A further problem with power supplies, particularly on board ship, is due to the susceptibility of micros to electromagnetic interference (EMI). This is due to the fact that the energy content of signals within micro systems is comparable to that of the interference. It is, therefore, necessary for the power supply unit to suppress any mains-borne EMI. Similarly the overall system needs to be protected from radiated EMI.

The subject of EMI susceptibility testing and standards is dealt with in Appendix C.

Types of Memory:

The types of device used to store information in a microprocessor system vary according to the application, the number of similar systems to be produced and the degree of reliability required. A range of memory devices is shown in Fig. 6 where they are presented in order of permanence of content, the most transitory being on the left.

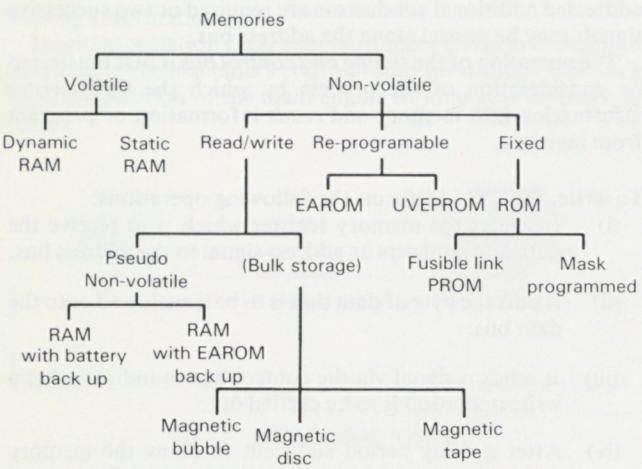


Fig. 6 Types of Memory

The major division of memory types is between devices which lose their stored information when the power supply is removed (termed *volatile*) and those which do not. Another division exists between those types which connect directly with the system's address and data busses, and those such as the magnetic tape, disc and bubble memories which require special interfacing circuits.

A semiconductor memory device to which the microprocessor can write information as well as reading information from it is known as a Random Access Memory (RAM). This signifies that any location in such a memory may be chosen at random and immediately accessed for storage or retrieval of its contents. The access time for RAM is a few hundred nanoseconds (10^{-9} seconds), a range of speeds being available to suit particular system needs. The faster devices are more expensive.

In a static RAM each binary digit is stored in a latching circuit which may be set to logic level 1 or reset to logic level zero when addressed and remains unchanged at all other times so long as the power supply remains on.

In a dynamic RAM, which is less expensive to produce than the static type, information is stored as minute electrical charges on microscopic capacitors; logic level 1 for capacitor charged, logic level zero for capacitor discharged. The charge tends to leak away so that it is necessary every few milliseconds to check which capacitors are charged and restore their charges to the initial level. This process may be carried out by an external *refresh* circuit or one which is integral with the memory chip or in some systems by refresh circuitry incorporated in the microprocessor.

Where the volatile nature of RAMs is not acceptable they may be rendered immune to loss of external power supply by connection of a small back-up battery, usually soldered to the printed circuit board (PCB) on which the RAM is mounted. For dynamic RAMs the refresh circuit must also be provided with back-up power.

Much of the information used by a microprocessor system will not require to be altered during the operational life of the system. This includes data on conversion factors and physical constants and also the monitor program and interpreter which enable the system to be programmed in more sophisticated languages than the machine code used by the microprocessor itself. Information of this nature is stored on Read Only Memory (ROM) devices and is known as *firmware*. The zeros and ones that constitute each byte of information in a ROM, are determined by connections within the microcircuit on the chip. For applications where many thousand devices will be produced the internal connections are most economically made at the production stage by generating a special mask for printing the microcircuit. For smaller production quantities a general purpose circuit is produced which can be programmed by the user. This is a Programmable Read Only Memory (PROM). As produced and PROM has a zero in every digit position. A digit 1 is produced at each required location by melting a connecting link in the microcircuit by means of a brief pulse of current. Once programmed, the contents of neither type of ROM can be erased so system modifications necessitate the replacement of the device by another containing the new information.

For system prototyping purposes, when several successive changes of program or data are likely to be required, it is more cost effective to use devices in which the information content can be erased and the device re-programmed. The first such type of device developed for general use employs ultra-violet radiation as the means of erasure and is consequently known as an Ultra-Violet Erasable Programmable Read Only Memory (UVEPROM). Erasure of the stored information is effected by 20 to 30 minutes exposure of the chip to the emission of an ultra-violet fluorescent lamp through a transparent window in the top of the package. Individual bytes of stored information cannot be selectively erased. A UVEPROM is electrically programmed and requires an additional +25V supply for that purpose. Programming is usually carried out by means of a separate piece of equipment from which the UVEPROM is transferred to a socket in the operational system.

A more versatile device has since been developed which is known as an Electrically Alterable Read Only Memory (EAROM). This too is programmed electrically, requiring a 21V supply but in this case the process may be performed in situ. Erasure is also carried out electrically and either a single byte or the whole content may be erased in a few milleseconds. There is a limit to the number of times that an EAROM may be reprogrammed so the device cannot be used as a non-volatile RAM. It may, however, be used as a back-up for a volatile RAM. In this case when mains power failure is detected the contents of the RAM are dumped to the EAROM before the energy stored in the power supply unit is dissipated. On restoration of power the information is transferred back to the RAM.

The access time required for reading a byte of information stored in EAROM or UVEPROM is a fraction of a microsecond and these memories both have a guaranteed information retention period of ten years.

For the permanent storage of large quantities of data or program information some form of magnetic medium is employed. This may be cassette tape, flexible ('floppy') disc, or magnetic bubble memory. Smaller versions of the rigid Winchester discs used on mainframe computers may also become accepted by micro system designers in the future. For the marine environment, where high humidity and vibration levels may be encountered, magnetic bubble memories, being completely non-mechanical, would be an obvious design choice but for their present high cost. However, as production quantities of magnetic bubble memories increase for defence applications the cost factor may become more favourable.

In marine machinery control and alarm applications magnetic disc and tape storage is unlikely to be employed as on-line memory. Their principal functions are to retain copies of the system program where the working program is held in RAM and to accept logging information for subsequent analysis by another computer.

Input/Output (I/O) Circuits:

Within a microcomputer system information is transmitted very quickly and in parallel form. Each digit of data is present simultaneously on its own individual conductor in the data bus for a fraction of a microsecond. Without special interfacing circuits, data in this form is incompatible with any other equipment except another computer. Interface circuits are connected to the data, address and control busses of the microcomputer system. Inputs are read by the microprocessor in the same way as a byte of data in memory and output data is written to the circuit's address in a similar manner to storing data in memory.

For mechanical devices such as keyboards and printers the process is slowed down by latching the data into a parallel output register which holds it long enough for the mechanical parts to respond. The interface circuit is adaptable and may be used as an input or an output device according to instructions given to it by the microprocessor from the system program.

These circuits are known variously as Programmable Peripheral Interface (PPI) or Peripheral Interface Adaptor (PIA) devices according to the manufacturer.

For recording data on a single channel tape recorder or for transmission via co-axial, optical or satellite links the digits must be presented sequentially in time, i.e. serially. A general purpose circuit is used for this function so that transmission speed and data verification methods may be selected via the program. The device is known as a Universal Synchronous/Asynchronous Receiver/Transmitter (USART).

The recording of data onto discs and the retrieval of such data is controlled by a Disc Operating System (DOS) program, which is available in a pre-programmed ROM.

For output to a visual display unit (VDU) either Red/Green/Blue video signals or modulated UHF (i.e. television) signals are produced by special purpose chips which may include character generators for letters, digits and graphical symbols.

The peripheral equipment above is such as would normally be associated with a data processing microcomputer. For machinery control and alarm applications other additional circuits are required. On/off signals to operate solenoid valves will require driver circuits of appropriate power. These signals and inputs from switches (temperature, pressure, level, etc) will use an I/O device such as the PPI or PIA but, in order to isolate the microcircuits from the higher voltages used on machinery, opto-isolators are interposed. These consist of light emitting diodes (LEDs) and photo transistors encapsulated together so that the only medium of connection is light. These give typically 1,5kV electrical isolation.

Where the input information is in analogue form, for example, 0-10V or 4-20mA instrumentation signals representing pressure or temperature etc., the analogue signals have to be converted to parallel digital signals by Analogue to Digital (A to D) converters before being read into the system via a PPI/PIA circuit. Similarly for an analogue output control signal a Digital to Analogue (D to A) converter circuit is required. Converter circuits can be shared among a number of signal inputs or outputs by means of signal selection and storage circuits.

2.4 Microcomputer Internal Operations

When the power supply is connected to a microcomputer system it initiates a reset sequence which sets to zero the register known as the program counter (PC). The information in this register is the address of the next instruction in the memory which the system is to execute. At start-up, therefore, the system is forced to commence reading its program at address zero.

The byte of program information at the first address is read and temporarily stored in the Instruction Register (IR). The PC is incremented by one before the instruction is decoded and executed. The first byte of instruction may call for up to two more bytes to be read and stored in order to complete the instruction. For instance, the instruction to read data from a particular address in memory will have 3 bytes. The first defines it as a read operation and indicates which of the internal registers of the processor is to receive the data, and the other two bytes are required to indicate the address from which the data is to be read.

With an 8-bit microprocessor there could be up to 256 possible one byte instructions. These are known collectively as the instruction set for that particular type of processor. The 8-bit instruction bytes may be represented as two digit hexadecimal numbers (*see* Appendix A), known as operation code (op. code) or machine code, but to render them more intelligable to programmers they are given abbreviated descriptive titles called mnemonics. These are of the form 'MOV B, C' which is the instruction to move the byte of data in register C into register B. The majority of microprocessor instructions are of this very simple form moving data between the several internal registers or to and from memory. One particular type of register, the accumulator, may be used to perform addition, subtraction or comparison and the logical functions AND, OR or EXCLUSIVE OR using its own data content and that of another specified register or memory address.

The decision-making ability of computers is due to *conditional jump* instructions. These cause the computer to branch to another part of the program by inserting the address of the beginning of that part in the program counter. Whether the jump is made or not depends on the result of a previous arithmetic or logical operation and the criterion may be selected from such conditions as the result being positive, negative or zero, or whether the previous operation produced a carry bit.

After executing an instruction, but before fetching another, the microprocessor tests to see if there is an external 'interrupt' signal. These signals are used by peripheral equipment such as keyboards to indicate to the microprocessor that there is data to be read in from the device, as this must be done quickly before it is lost. On receipt of an interrupt signal the contents of the program counter are saved in a reserved part of the memory termed the *stack* and another address is inserted in the PC so that the system jumps to the subroutine required to process the incoming data. After completion of the subroutine the former contents of the PC are restored so that the system resumes following the main program where it left off. Interrupts may be enabled and dissabled by instructions in the program, they may also be assigned priorities so that a higher priority interrupt may intervene in the subroutine of a lower priority interrupt.

2.5 Programming:

Programming Languages:

In spite of the large number of operations that can be called up by the instruction set of a typical microprocessor, the types of task that may be carried out by a single instruction are severely limited. Multiplication and division, for instance, require subroutines of several instructions to carry out the necessary number of shift and add/subtract operations. Programming would be a very slow process if every such function had to be written out in machine code whenever it was required.

One method employed to speed up the creation of programs is the use of an 'assembly language'. This allows the programmer to write instructions in the form of mnemonics and to label parts of the program so that they may be used as subroutines called into use by instructions at several points in the main program. The subroutine for multiplication would thus only have to be written out once, but could be used any number of times. The program that converts an assembly language program into machine code is called an assembler and may be incorporated in the firmware of the working computer or, alternatively, it could be in another computer, such as a microprocessor development system, when only the final machine code program would be transferred to the working computer.

High level languages such as Basic, Pascal, Forth and Coral 66 provide a better aid to programming. With these languages instructions approximate more closely to the English language and it is not even necessary for the programmer to write out the multiplication subroutine because it is already incorporated in the interpreter program for the language along with many others. An instruction such as X = A * B will automatically call up the multiplication subroutine. In addition to the large number of mathematical logical and conditional jump functions available, a high level language provides a valuable organizational facility. Each line of instruction is numbered by the programmer in order, but with gaps left for subsequent insertions. Instructions such as jumps refer to their destinations by line number and not memory address so that when instructions are added or deleted it is not necessary for the programmer to alter all the jump destination data, this is done automatically. The interpreter, or compiler program, for a high level language includes several tests to indicate programming errors as each line of instruction is initially put into the system. This makes the process of *debugging* a program in high level language very much simpler than for one in machine code.

There are some disadvantages to the use of high level languages:

(i) The interpreter program may occupy about 16k of the memory which reduces considerably the space available for working program.

(ii) The program itself will occupy more memory space than would the equivalent in machine code.

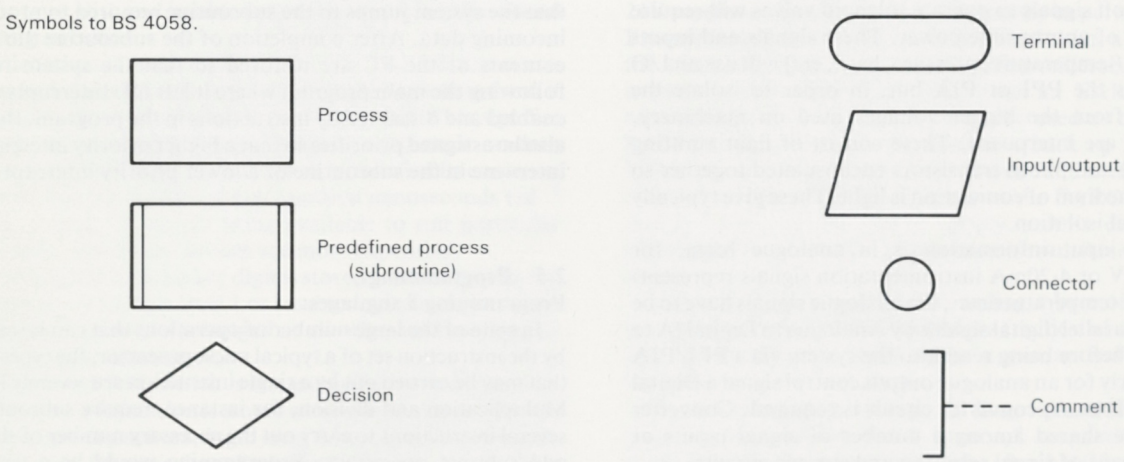
(iii) Execution of the program is generally slower than for one in machine code, but speed varies considerably according to the particular language.

Development of Programs:

Before any but the simplest programs can be written it is necessary to analyse the specified system requirements and express them in ordered sequences of simple operations and straightforward yes/no decisions based on information available to the system. All possible operating modes must be considered and positive steps taken to prevent the occurrence of operations that are not required.

The resultant product of the above process is known as an *algorithm*. Rather than present the information as a written list of procedures it is more usual to depict an algorithm by means of a *flow chart* or *flow diagram*. The shaped symbols used in the compilation of a flow diagram are shown in Fig. 7, and an example of a flow chart for a U.M.S. alarm system to comply with Part 6, Chapter 1, Section 4.2 of the Society's Rules is shown in Fig. 8.

At this stage of program development the process is completely independent of considerations of particular programming languages to be used; indeed the system as described on a flow chart might well be executed by means of electromechanical components instead of a microprocessor system. For this reason flow charts present a convenient means of system description and in some cases they are being submitted by manufacturers for plan approval. Once the algorithms for a system have been developed it becomes a relatively easy matter to translate them into a program of a particular language.



Note: The size of the symbols may be varied.
Symbols should be linked by flow lines.

Fig. 7 Symbols for Flow Charts

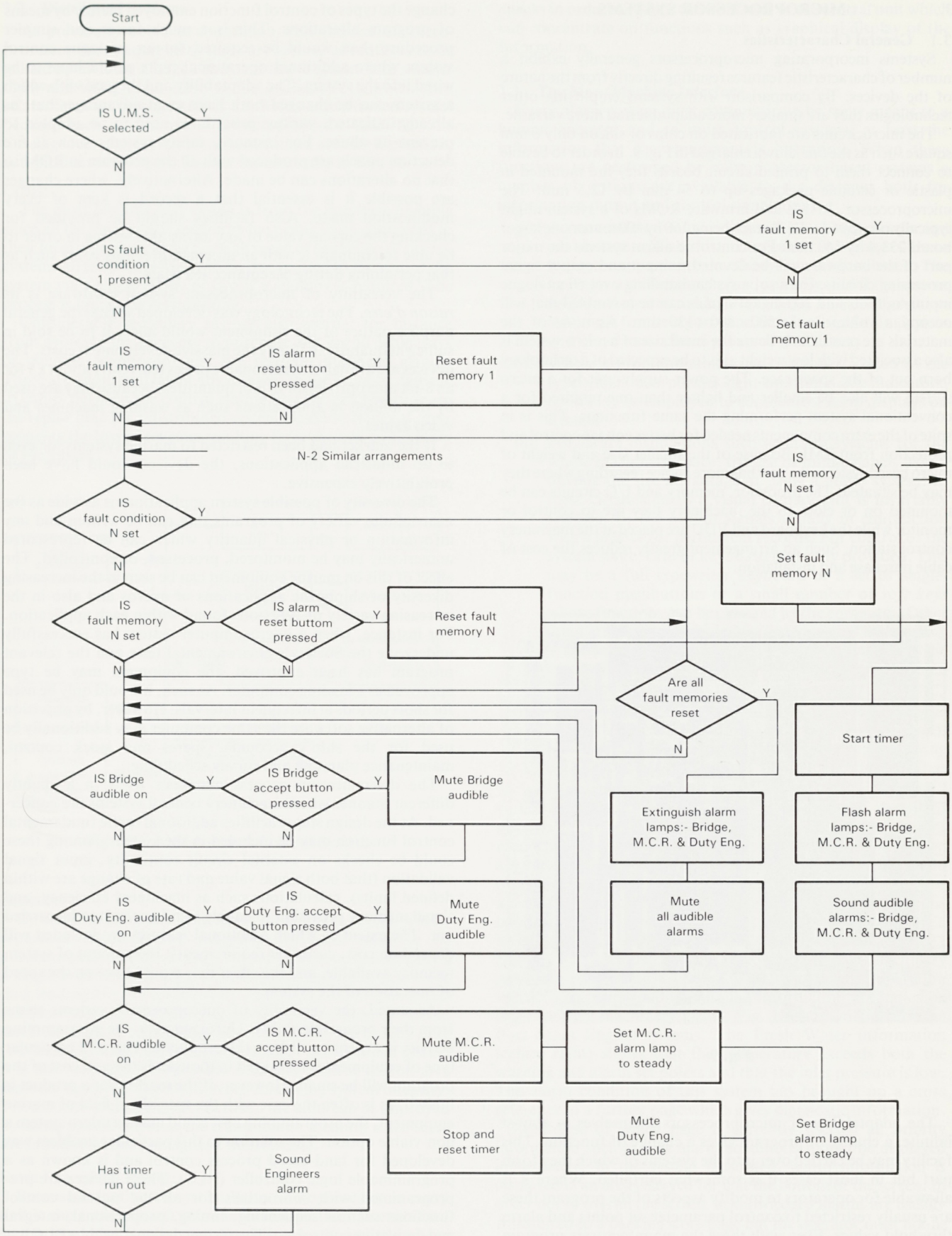


Fig. 8 Flow Chart of U.M.S. Alarm System

3. MICROPROCESSOR SYSTEMS

3.1 General Characteristics

Systems incorporating microprocessors generally exhibit a number of characteristic features resulting directly from the nature of the devices. By comparison with systems employing other technologies they are smaller, more adaptable and more versatile.

The microcircuits are fabricated on chips of silicon only 6 mm square such as the one shown enlarged in Fig. 9. In order to be able to connect them to printed circuit boards they are mounted in plastic or ceramic packages up to 54 mm by 12,5 mm. The microprocessor, RAMs and firmware ROMs of a system might typically occupy four PCBs each being 160 by 100 mm or one larger board 233,4 by 160 mm. For control or alarm systems the major part of the hardware will be devoted to input and output signal processing circuits. Even so, a system handling over 60 analogue inputs/outputs and 200 digital signals can be assembled that will occupy a volume only $500 \times 200 \times 130$ mm. As none of the materials are particularly dense the small size of a micro system is also associated with low weight as is to be expected of a technology born out of the space race. The power supply unit for a micro system will also be smaller and lighter than one required for a conventional system performing the same functions. This is in spite of the extra components needed for better voltage control and protection from EMI. Because of the smaller size and weight of micro based systems the user has more choice regarding where they may be situated. The processor, memory and I/O circuits can be mounted on or close to the machinery they are to control or monitor while the keyboard and VDU are placed at the machinery control station. Such an arrangement greatly reduces the cost of cable purchase and installation.

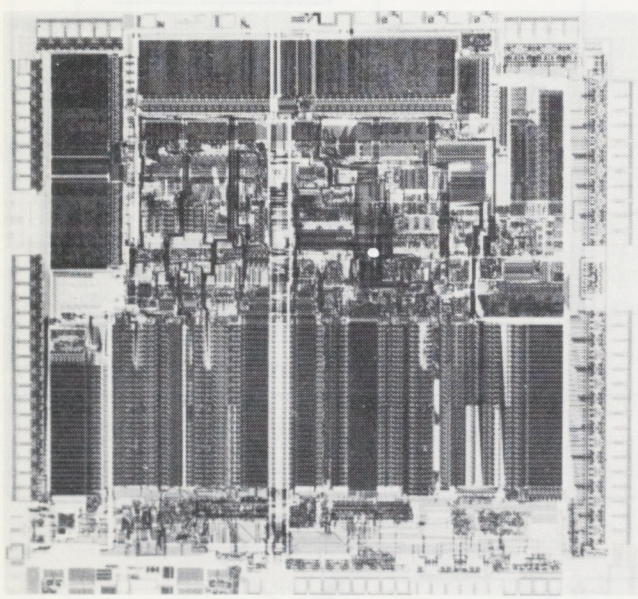


Fig. 9

The adaptability of microprocessors themselves is almost infinite, a change of program gives a change of function. This facility may be carried over into the systems of which they form part but in most cases it is somewhat curtailed. Where it is allowable for operators to modify aspects of the program these are usually restricted to control parameter set points and alarm threshold values. Even with these the manufacturers program may only permit a value to be selected within a specified range and generally it is necessary to operate a key switch before any alterations can be made. However, should more radical modifications be found necessary, for instance while commissioning the system, the manufacturer's representatives can change the types of control function employed merely by means of program alterations. This is a much faster and simpler procedure than would be required for an analogue control system where additional operational units would have to be wired into the system. The adaptability and the ease with which a system can be changed both have great advantages but, as already indicated, various procedures need to be adopted to prevent its abuse. For instance, safety systems such as fire detection panels are produced with all the program in ROM so that no alterations can be made. Alternatively, where changes are possible it is essential that a record is kept of every modification made. Also facilities should be provided for checking the current value of any adjustable setting in order to be able to compare it with an accepted previous value such as that pertaining during acceptance sea trials.

The versatility of microprocessor system hardware is its *raison d'etre*. The technology was developed so that the general purpose nature of the equipment would allow it to be sold in sufficient quantity to justify the massive development costs. The devices are available at reasonable prices (currently about £5 for an 8-bit microprocessor in unit quantities) because they are used by the million in applications such as washing machines and video games.

If the market had been restricted to marine systems, or even to all industrial applications, the devices would have been prohibitively expensive.

The diversity of possible system applications is as wide as the near-infinite variety of programs that can be written and any information or physical quantity which can be represented numerically may be monitored, processed, or controlled. The effect of this on marine equipment can be seen in the increasing diversity of shipborne applications of micros and also in the increasing variety of functions found within each application. For instance, when a microcomputer system has successfully undergone the Society's environmental tests and the relevant program has been approved, the equipment may be type approved as a loading computer. As such, it would only be used for short periods at infrequent intervals. However, by provision of alternative software the same computer may additionally be used for the ship's accounts, spares and stock control, maintenance planning and survey scheduling.

The diversification process manifests itself in a slightly different manner where machinery control systems are concerned. At the design stage facilities additional to the fundamental control function may be included in the system. Among these could be checks on external circuit continuity, input signal validation (that both signal value and rate of change are within defined limits), calculations such as machinery efficiency, and signal memory provision to enable trend analysis to be carried out. The extent to which additional features are included will depend on cost, customer requirements, the amount of system memory available, and the effect they would have on the speed of operation of the system.

As stated, the versatility of microprocessor systems stems from their programmability. Unfortunately, the programming activity is expensive. Where the production run of a particular type of equipment is measured in thousands the unit cost of the program will be small. However, if the market for a product is limited, as is often the case with the specialised field of marine equipment, the programming cost could make a micro system a non-viable option. The solution to this particular problem was developed for land-based process control and is known as a programmable logic controller (PLC). These devices are pre-programmed with subroutines for all the normal control functions such as sequencing, timing, proportional, integral and derivative control etc. The system designer using a PLC has only to define which functions are to be performed on each input signal and to which output the result is to be connected in order to achieve a working system. Arrangements are usually such that a working system can be configured without the need for any previous digital programming experience.

3.2 Distributed Systems

As previously noted in connection with the size of microprocessor based equipment there are several advantages to be gained by dividing a large control or alarm system into smaller units and siting them close to the equipment to which they relate. Such an arrangement is known as a distributed system because each unit contains a microprocessor and thus the 'intelligence' of the system is not centralized at a single position. A typical arrangement is shown schematically in Fig. 10.

Costs:

The most obvious cost saving is from the purchase of cable since all the sensors and actuators have only to be connected to their local unit. Because of the high speed of operation of microsystems all the sensor data can be transmitted to the rest of the system via a single cable, or two if a standby is required. The process is known as *multiplexing*.

Considerable secondary savings also accrue, for instance from avoiding the necessity to purchase and install cable trays or conduit, waterproof and fire resistant bulkhead glands. There are additional latent advantages. In the event of damage to cables between the control station and the machinery space the repair time for a distributed system would be minimal, thus reducing the loss of revenue resulting from the non-availability of the vessel.

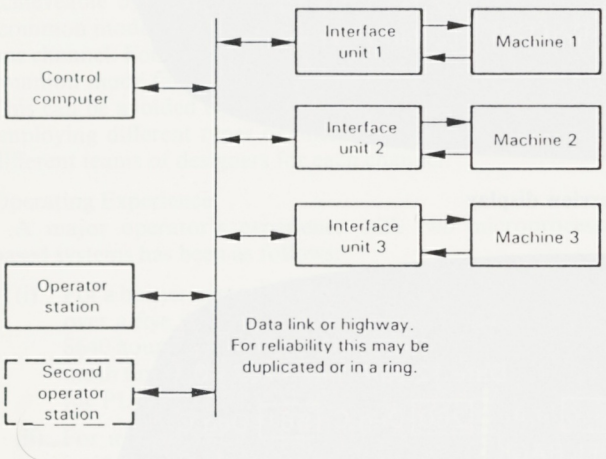


Fig. 10 A Distributed Control System

Security:

By distributing control and alarm functions to several widely separated locations and designing the local units to be autonomous, systems can be protected from total failure due to a single event such as a fire at the control station or in a cable duct leading to it. This eliminates a major hazard of centralized systems while still allowing control and monitoring to be carried out from a single central position. Since there are usually only two data highways connecting the units of a distributed system it is not very costly to provide a second control station at a separate location, thereby, further enhancing system integrity. The security of data transfer between the units can be improved by using optical fibres as the transmission medium since these are immune to electromagnetic interference.

Extra Processing Power:

Because a distributed system has a microprocessor in every unit it can handle much more information than a centralised system could with only one. For instance, if a single micro system can interrogate 200 sensors per second it could alternatively interrogate 200 local units per second each connected to 200 sensors, a total of 40 000 points.

In practice, the additional power is employed differently so that local units perform signal pre-conditioning and validity checks in order to reduce the workload of the central unit which can concentrate on functions such as graphical display of the information.

3.3 The Man/Machine Interface

Every alarm system must communicate by some means to a human operator and so must control systems, at least the information that the equipment is operating. When these functions are performed by microprocessor based systems a number of options are available to the designer both for information output and control signal input.

(i) A conventional mimic diagram panel with lamps and pushbuttons. With this arrangement it is impossible to tell by the appearance that the system is micro based. The operator uses the panel exactly as he would if the system employed electro-mechanical relays. This configuration is suitable for the control and monitoring of a single item or a closely associated group of machinery.

(ii) Where a programmable logic controller is used of the type which incorporates light emitting diode indicators, these may be employed to supplement lamp displays on a panel.

(iii) For larger installations such as alarm systems for the whole machinery space, the use of mimic panels would obviate the size advantage of using a micro system. In these circumstances a visual display unit is invariably selected for the output signals usually in conjunction with a printer for permanent records. For control of the system some form of keyboard is usually provided. This may be a full typewriter keyboard or a set of single-function pushbuttons or a small number of *soft keys* whose functions can be changed by the computer. Other input arrangements could be a *light pen* used by touching it against the VDU screen opposite a statement of the required action to be taken, or a *touch-screen* for which the selecting element is a human finger.

(iv) Voice recognition has been used as an input for bridge control and could be employed for machinery systems. Similarly speech synthesis could be used for giving detailed information about alarm conditions as has already been done in automobile systems.

Careful consideration has to be given to the design of systems employing VDU output. In spite of the smaller symbols used it is difficult to convey as much information at one time on a screen as is possible with a large mimic panel. To avoid overcrowding the screen the display information has to be appropriately sub-divided into several 'pages' each with the necessary cross references. Two pages of display for a hovercraft alarm and monitoring system are shown in Figs. 11 and 12. Fig. 11 illustrates the indication of main machinery parameters including a line to mark their normal operation values. The pages holding detailed information are indicated opposite each machinery group. Fig. 12 shows details for the Port Main Engine systems. The Fresh Water information (centre right) shows that the temperature exceeds both the warning and alarm set points and that the inlet pressure is low. The alarm condition of this system has brought up a cross reference to a further page which gives diagnostic information.

Regardless of which page is currently selected all priority information such as new alarm conditions should be displayed immediately. In the system illustrated, alarm information is displayed in an area reserved for it at the bottom of the screen. In order not to overfill the screen, acknowledged alarms are usually transferred to a backing store page but the operator must not be allowed to forget the existence of any uncorrected fault conditions.

3.4 Reliability

As with any new technology the prospective user of micro systems is likely to want to know how reliable they will be. The

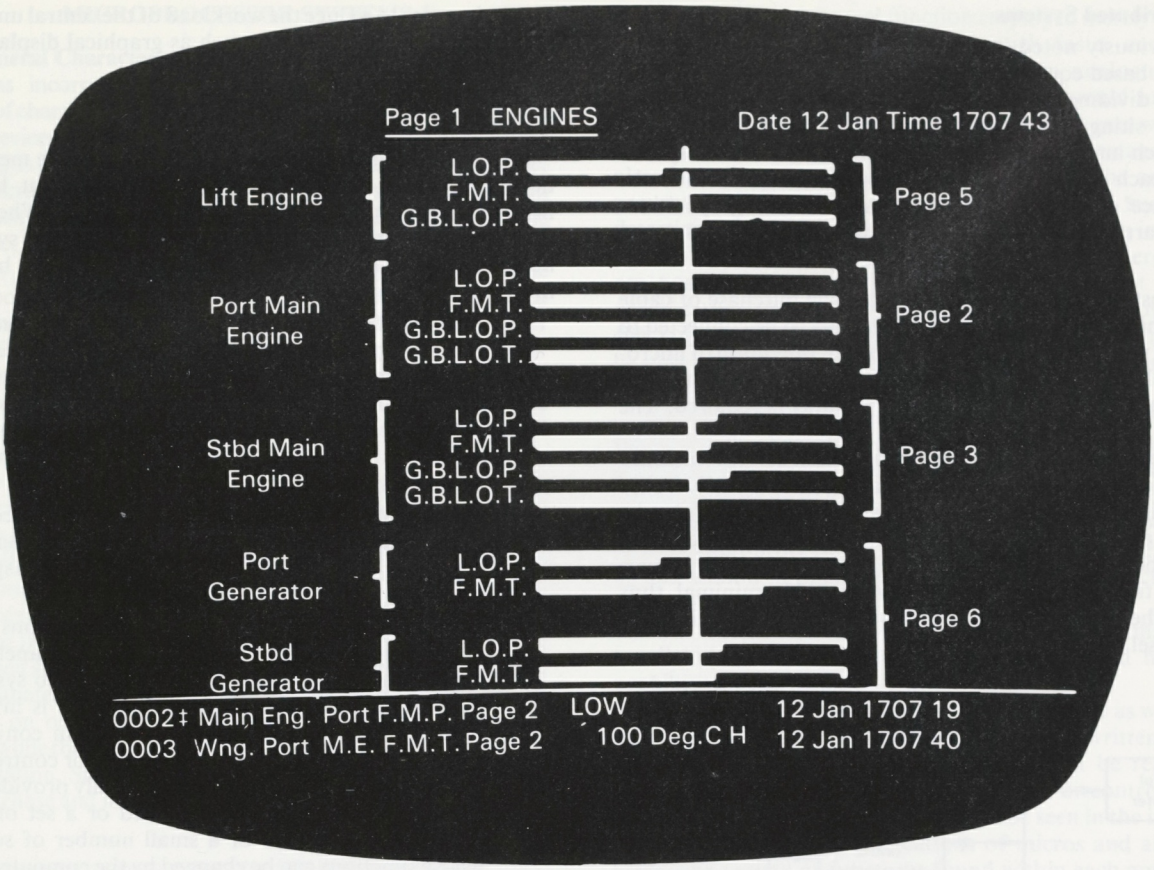


Fig. 11 Machinery overview display

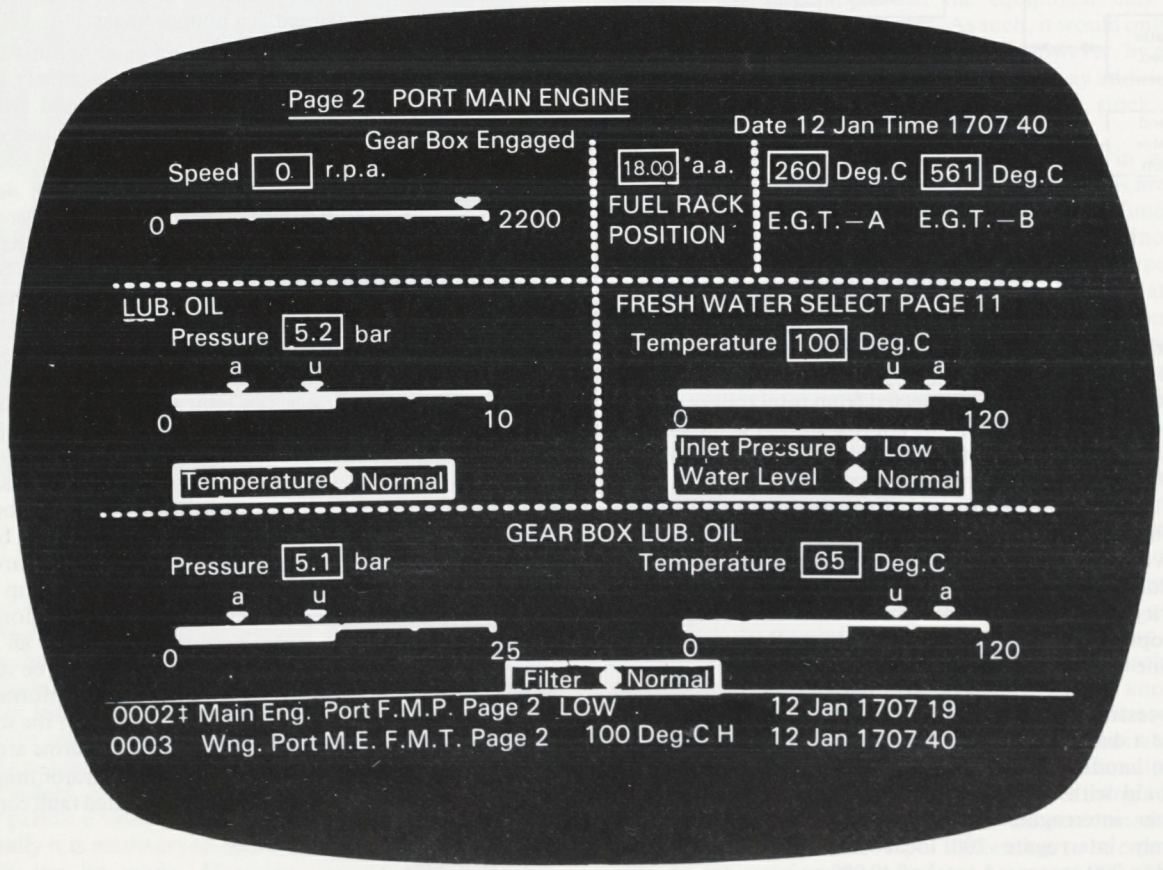


Fig. 12 Detailed display for one main engine

absolute figure for reliability of a particular system will depend on the number, type and complexity of the circuits involved. However, for a system performing a given task there are two approaches which may be used either separately or together to effect relative improvements in reliability. The adoption of either will incur additional cost.

Component Reliability:

The first approach is to use only high reliability components in the system. These have been put through a series of test procedures one of which is a 'burn-in' process in which the component is operated for some time at a temperature near its upper limit. This eliminates those components which would constitute the initial part of the relative failure rate curve. Table 1 due to Wright[1]* of the Systems Reliability Service of the U.K. Atomic Energy Authority shows the relative improvements in microprocessor hardware reliability achieveable by various levels of testings to American MIL standards, together with the relative increase in component cost. Levels B and A include the burn-in process.

System Redundancy:

The second appoach is to provide a standby system to automatically take over in the event of a failure of the normal system. Where system failure may be difficult to define or monitor, it may be necessary to provide a third system and perform a 2 out of 3 voting operation. The reliability achieveable by this approach is limited by the possibility of 'common mode failures' where a single fault affects more than one channel. For micro systems the program may be a source of common mode failure if each channel has the same program. This can be avoided by introducing diversity to the system by employing different types of microprocessor programmed by different teams of designers for each channel.

Operating Experience:

A major operator's experience with two microprocessor based systems has been as follows:

(i) For a burner management system employing dual PLCs, over a five year period a mean time between failure of 8640 hours was recorded. Perhaps more significantly the mean time to restart was only 8,8 minutes. Fig. 13 shows the PLCs of this system.

(ii) For a boiler and turbine control system a total of 32 incidents were recorded over a period of about two years, only two of which resulted in boiler shut-down. A significant number of the failures, six in number, were associated with peripheral devices such as keyboard, VDUs and light pen and thus did not directly affect the operation of the machinery.

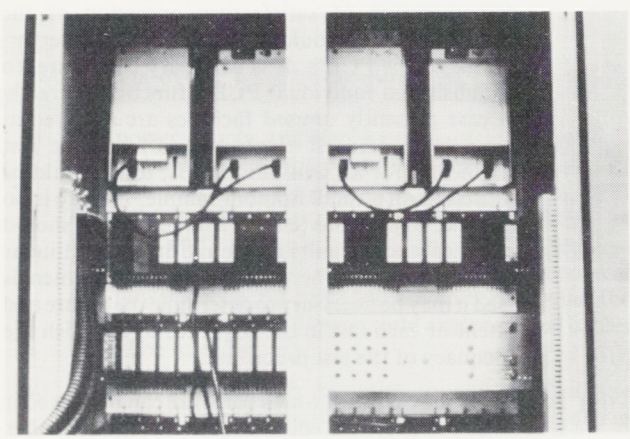


Fig. 13

*Numbers in parentheses indicate references.

Table 1 Relative cost and reliability of screened devices

Screen level (MIL-HDBK-217C)	Specification	Relative Cost	Relative Reliability
D-1	Commercial, plastic encapsulated	1	1
D	Commercial, hermetic package	1-2	2
C-1	Vendor equivalent of C		2,7
C	MIL-M-38510 Class C	2-4	4,4
B-2	Vendor equivalent of B-1		5,4
B-1	MIL-STD-883 method 5004 Class B screened	4-6	11,7
B	MIL-M-38510 Class B		35
A,S	MIL-M-38510 Class S	8-20	70

4. RULE REQUIREMENTS AND SURVEYS

4.1 Rules

The advent of the microprocessor has necessitated a further stage in the evolution of the Control Engineering Rules. The additional requirements for programmable electronic systems are set out in Part 6, Chapter 1, Section 2.9 of the rules, among the other essential features for control, alarm and safety systems. As with other Rules these are considered to be minimum requirements and are intended to allow considerable flexibility to system designers. Some aspects of the new Rules are discussed more fully below.

Documentation:

The list of plans required to be submitted (Part 6, Chapter 1, Section 1.2.2) has been supplimented by the inclusion of Section 1.2.5 listing such documents as are necessary to define the software functions of programmable systems. These may be flow charts (*see* 2.5 above) or logic diagrams using the symbols shown in Fig. A.1 of Appendix A, or in the case of PLCs the data may be presented as ladder diagrams like those of equivalent relay systems. Details of the self-monitoring arrangements are also required.

The Single Fault Philosophy:

The Control Engineering Rules have been developed almost completely on the basis of a single fault philosophy. This accepts that faults will occur in machinery, its associated control system, alarm and safety systems, but only in one such unit at a time. If the machinery or control system develops a fault the safety system will still be operational to prevent a dangerous situation and the alarm system will inform responsible personnel. If the alarm or safety system is at fault it is assumed that a machinery or control malfunction will not occur simultaneously.

For a single fault philosophy to hold true it is necessary that control, alarm and safety systems be segregated so that failure in one system will not affect another. In a micro based system it would be very simple, and indeed tempting from a cost point of view, to integrate all these functions into a single system but this is now ruled out by the new Rule requirement of 6.1.2.9.2. There are, however, a number of possible system configurations that would satisfy this requirement. For instance in the case of two items of machinery with control and alarm functions provided by two microprocessor systems the following arrangements would be acceptable:

(i) One micro system controlling both machines with the other providing alarm monitoring for both machines.

(ii) Each micro system controlling one machine and monitoring the other.

(iii) One micro system controlling and monitoring both machines with the second micro as a duplicate system on stand-by with automatic change-over in the event of failure of the normal system.

Self Monitoring Arrangements (6.1.2.9.4):

Micro systems require different self-monitoring arrangements from those applicable to conventional alarm systems. It is necessary not only to check the external circuit continuity, but also the correct functioning of the microprocessor itself. This is usually carried out by an independent circuit called a watchdog. This in its simplest form consists of a resettable delay timer which gives an alarm unless it is repeatedly reset by signals regularly put out by the microprocessor system. In the event of either a hardware fault or software error causing the system to fail to repeat its cycle of program instructions the watchdog circuit will not receive its signal and so will raise an alarm.

In distributed systems the validity of data transmitted between units should also be verified. The simplest means of checking is by the use of a *parity bit*. As the bits that constitute the data are serially transmitted the number of digits which are one are counted and for 'even parity' an extra digit one is added if required to make the total an even number. In this way every transmission will consist of even numbers of digit ones. The receiving unit counts the incoming digits and indicates a fault or requests re-transmission if there is not an even number of digit ones received. A single parity bit will detect the presence of a single error but more sophisticated methods employing several parity bits are capable of detecting multiple errors in a transmission, and may even locate which bits are at fault.

Fault Location:

It will be noted from 6.1.2.9.5 that the location of a hardware fault is to be indicated to a level compatible with the equipment's designed repair/replacement policy. This is considered necessary for microprocessor based equipment since the novelty and complexity are such that it would be unreasonable to expect non specialised personnel to be able to locate hardware faults without the aid of built-in test facilities. In the absence of such assistance the equipment could be inoperable for long periods of time. This is not an onerous requirement and many manufacturers already include these facilities since their reputations would also suffer should their equipment be subject to undue down time.

Power Supplies:

The power supply arrangements and their alarm requirements (6.1.2.9.6, 7 & 8) are slightly more onerous than for other types of system. The standby power supply is now to be monitored for failure in addition to the normal supply so that, should change-over be necessary, it will be to a known healthy supply. The Rules do not require change-over to be no-break, or that an uninteruptable power supply unit be fitted. For this reason the requirement has been included that program and data are to be protected from corruption by loss of power.

Program (6.1.2.9.9):

Where any part of the program is stored in volatile memory, even though it may be protected from power loss by local battery back-up, it is considered essential that facilities are provided to re-program the system. This is to correct a situation that might arise due to program corruption by EMI or tampering.

4.2 Surveys

It has to be admitted that the task of surveying systems based on microprocessors is more difficult to carry out adequately than is the case with traditional technologies. Testing for performance to specification, that the system will do what it is designed to do, is the same in both instances but the problem with micro systems is to ensure that they will not do what they are not supposed to do since there is such a large number of permutations of inputs and internal signals.

System hardware will probably have been tested by the manufacturer as individual printed circuit boards using some form of automatic test equipment. Whether or not this has been done, works tests should be carried out to the approved schedule on any major system in order to prove the effectiveness of the program which is unique to the particular application.

Survey at the Manufacturer's Works:

The purpose of works testing is to ensure, as far as practicable, the correct assembly and operation of a system before its delivery to the ship. Tests may have to be limited to functions internal to the system if the associated machinery is not available. In these circumstances the controlled equipment may be simulated by another computer system. It should be borne in mind that both computers, the control system and the simulator, will probably have been programmed by the same design team so that there is a possibility of a common error. It has been shown by Endres[2] that the largest single source of software errors lies in the specification of the system, which will be a common feature of both the system under test and the simulator.

The following procedure should be observed, as appropriate, when surveying micro equipment at a manufacturer's works:

(i) Determine the QA position of the hardware by reference to the Manufacturer's documentation.
  (a) Is the equipment Type Approved by the Society, or has it been approved previously for installation in a classed vessel? This would indicate that the firm is familiar with the Society's Rules and requirements.
  (b) Are there QA certificates relating to high reliability components, and if so, are they in accordance with specified reliability requirements.
  (c) Are there performance test certificates relating to individual units and PCBs? This will affect the degree of testing requiring to be witnessed.

(ii) (a) Examine the equipment to ensure that it is complete and of good workmanship. PCBs should be particularly checked for solder bridging where tracks pass between the pins of ICs and their sockets and for the quality of through-hole plating.
  (b) In systems using multi-purpose or multi-channel PCBs it is unlikely that all the facilities of each PCB will be employed. In these circumstances a demonstration of satisfactory operation of the complete system would not fully prove the performance of the PCB's. It is necessary, therefore, to establish that individual PCB's function correctly in case presently unused facilities are required at some later date. If there are performance test certificates for all units and PCBs, tests should be witnessed on a small random sample. If there is no evidence of previous testing, a larger sample should be taken and if faults are found in this, all items should be tested. Where automatic test equipment is used it may be necessary to determine the nature and extent of each test in the sequence to establish the adequacy of the test procedure.

(iii) Because of the ease with which software can be altered it is necessary to check the edition or modification number of the program used.
  (a) The firmware in ROM should be identifiable by numbering on the integrated circuit packages or on the PCB.

(b) Program on tape or disc should be clearly labelled. The program should not have been altered significantly from that which received plan approval.

(iv) If any of the program is on tape or disc it should be read into the system at the start of the test so that the system is put into a defined state for the test.

(v) Note how secure any adjustable program parameters are; whether it is necessary to operate a keyswitch or input a code in order to make alterations and whether modifications are automatically recorded by a printer. Check that the process of making an adjustment to the program does not adversely affect the system's operational capability.

(vi) Test in accordance with the approved schedule if available, failing that, request the following:

(a) Demonstration of correct operation of the watchdog circuit.

(b) Demonstration of failure modes. Alarm systems are to fail to the alarm state and control systems to fail safe. The safe states of the various outputs should be defined in the schedule (e.g. for valves, fail to open, fail to shut or fail to last command).

(c) Demonstration of transfer of control to standby system (if fitted) with minimum disturbance.

(d) Demonstration of autonomous control by local units of a distributed system and change over to standby data highway.

(e) Power supply tests. Program and data should be retained in the circumstances of complete power failure. Normal operation of the digital system should re-start when the power supply is restored and control system outputs should be maintained in safe states.
Failure of each individual power supply should be simulated and should initiate an alarm.
Power supply input variations, for mains supply inputs apply voltage variations of $\pm 10\%$ with simultaneous frequency variations of $\pm 5\%$ or at least the manufacturer's specified figures.

(f) Tests with a variety of input conditions simulating both normal operation and abnormal conditions (e.g. simultaneous signals that a valve is fully open and fully shut).
All normal system functions should be tested and all alarm conditions.

(g) Demonstration of several examples of hardware fault location.

Survey on the Ship:

Two aspects of the installation should be checked before testing:

(i) The power supply and signal cables of micro systems should be installed in accordance with an appropriate code of practice to avoid EMI. For instance, IEC Publication 533 'Electromagnetic Compatibility of Electrical and Electronic Installations in Ships' requires (para 21.3(d)) signal cables to be separated from control and power cables by 500 mm, not to run parallel for more than 5 m, and to cross at right angles. Signal cables should be screened.

(ii) If air conditioning is essential to any part of the equipment, standby arrangements should be provided in case the normal air conditioning system fails.

The purpose of tests on the ship is to establish the compatibility of the system with the machinery it is to control or monitor and accordingly the procedure will differ in some respects from the works tests. Any aspects of the works tests omitted previously should be carried out before proceeding with ship tests.

(i) Check the edition of the program as before and have it read in.

(ii) Test in accordance with the approved schedule which should include:

(a) At an early stage a demonstration that the fail safe states of control outputs put the machinery into a safe condition.

(b) A demonstration of control transfer to standby system or local unit without undue disturbance.

(c) Operation of machinery throughout its normal range of parameters to demonstrate stability and accuracy of control.

(iii) Any program modifications found to be necessary should be recorded and if they affect program on tape or disc a corrected copy should be retained on the ship.

5. CONCLUSIONS

Having seen the advantages of microprocessor systems, such as their versatility, adaptability, reliability and relatively low cost, it can be appreciated that their use is bound to increase for shipboard applications as it has done ashore. The time may not be far ahead when only microprocessor systems will be economic propositions for control, alarm and safety functions for machinery and the analogue control system may go the same way as the analogue watch.

The Society has acknowledged this situation by drawing up Rules for control engineering equipment incorporating programmable electronic systems and surveyors who are likely to encounter such equipment would be well advised to familiarise themselves with this technology.

6. ACKNOWLEDGEMENTS

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Within the Society the author would also acknowledge the assistance of colleagues in the Control Engineering Department and the Technical Illustrators.

7. REFERENCES

1. WRIGHT, R.I., 'Microprocessor Hardware Reliability.' Report No. SRS/GR/60, Systems Reliability Service of United Kingdom Atomic Energy Authority. October 1982

2. ENDRES, A., 'An Analysis of Errors and Their Causes in System Programs'. Institute of Electrical and Electronics Engineers Transactions on Software Engineering, Vol. SE-1, No. 2. June 1975

8. GLOSSARY OF TERMS

ACCESS TIME The time from the receipt of an address by a memory element to the time for the data from the addressed element to appear at the output.

ACCUMULATOR A register that may be used as the source of one operand and the destination of results from device operations.

ACTIVE-HIGH Logic level 1 is in the active state.

ACTIVE-LOW Logic level 0 is the active state.

ADDRESS The coded location of one byte of memory.

ADDRESSING MODES Inherent, Immediate, Direct, Extended, Indexed and Relative. These are the modes specifying the addresses to be used in an instruction.

ALGORITHM A series of instructions or procedural steps for the solution of a specific problem.

ANALOGUE-TO-DIGITAL CONVERTER (ADC) A device for converting an electrical voltage or current signal into a binary number.

ARCHITECTURE The structure of a system.

ARITHMETIC LOGIC UNIT (ALU) An element that can perform several arithmetic and logic functions.

ARITHMETIC SHIFT

1. A shift operation (left or right) in which the value of the sign bit is maintained.
2. A shift that is equivalent to the multiplication of a number by a positive or negative integral power of the radix.

ASCII (American National Standard Code for Information Interchange) The standard code, using a coded character set consisting of 7-bit coded characters, used for information interchange among data processing systems, communications systems and associated equipment.

ASSEMBLER A computer program that is used to translate mnemonic instructions into their binary equivalent codes and assign memory locations for data and instructions.

ASSEMBLY LANGUAGE A language in which mnemonic instructions, labels and names are used. These can be translated by an assembler into a machine-code program.

ASYNCHRONOUS COMMUNICATIONS INTERFACE ADAPTER (ACIA) An interface chip designed to permit serial asynchronous data communication between peripheral equipment and a microprocessor.

ASYNCHRONOUS OPERATION Operation without using a timing reference.

BASIC An acronym for 'Beginner's Application Symbolic Instruction Code', a high-level programming language.

BAUD RATE The serial rate of transmission expressed in bits per second.

BINARY-CODED-DECIMAL (BCD) A code in which each decimal digit is coded using four weighted binary digits.

BENCHMARK PROGRAM A specimen program that is used to compare and evaluate microprocessors.

BIDIRECTIONAL BUS A bus along which signals may be sent in either direction, e.g. a data bus.

BINARY A number system with radix (or base) 2.

BIT A binary digit.

BRANCH INSTRUCTION An instruction used to make decisions in a program. Program operation departs from the normal incrementing of the program counter content by placing a new destination address value in the program counter when the program branch decision is reached.

BREAKPOINT A user-specified, temporary program halt used in program debugging.

BUS Parallel conductors connecting two or more devices.

BUS CONTENTION The situation when two or more devices are simultaneously attempting to place data on a data bus.

BYTE The group of eight bits considered by the microprocessor as a binary word.

CARRY BIT The status bit used to indicate the occurrence of a carry from the most significant bit in a word.

CENTRAL PROCESSING UNIT (CPU) Part of a computer system which contains the arithmetic/logic unit and special registers.

CHIP The substrate of a single integrated circuit.

CLEAR An input to a device that resets the state to 0.

CLOCK A periodic timing signal used to control a system.

CMOS DEVICES Complementary Metal Oxide Silicon logic elements constructed from N- or P-channel field effect transistors to provide lower power consumption and high noise immunity devices.

COMPILE The process of producing machine code from a program written in a high-level language. The process is carried out automatically using computer programs called compilers.

CORAL A high-level programming language designed for real-time computer applications.

COUNTER A device that changes one state after the application of each clock pulse. Normally its output indicates the total number of clock pulses received (up to its capacity).

CROSS ASSEMBLER An assembler designed to run on a computer other than the one for which it assembles programs.

CURRENT LOOP An interface connection that normally uses 20 mA current in the loop to indicate the logic 1 and zero current to indicate logic 0.

CYCLE TIME The time interval for one set of regular operations to be completed.

DEBOUNCE The conversion of mechanical contact bounce into a clean transition between the two logic states.

DEBUG Removal of programming errors.

DECIMAL ADJUST An operation to convert a binary result into a binary-coded-decimal result.

DELAY TIME The time between demand signal and appearance of a corresponding output response.

DEMULTIPLEXER A device that directs a time-shared input signal to several outputs in order to separate the channels.

DEVELOPMENT SYSTEM A microcomputer system designed for the development of microprocessor programs and interfaces.

DIGITAL-TO-ANALOGUE-CONVERTER A device for converting a binary number into an electrical voltage or current signal.

DIRECT ADDRESSING An addressing mode in which the address of the operand forms part of the instruction.

DIRECT MEMORY ACCESS (DMA) A method by which data is transferred between memory and input/output sections without microprocessor program involvement.

DUMP The process of transferring, en mass, the contents of memory and registers onto a magnetic tape or other form of backing store, or of directly printing the contents.

DYNAMIC MEMORY A memory that slowly loses its contents and, therefore, needs refreshing.

EAROM Electrically Alterable Read-only Memory.

EEROM / *E²PROM* Electrically Erasable Read-only Memory.

EDITOR A program that permits text material to be manipulated and allows corrections and changes to be made.

EPROM Erasable Programmable Read-only Memory.

FIRMWARE Microprograms implemented in read-only memory.

FLAG A flip-flop that is normally set to logic 1 after the occurrence of a specified event.

FLOWCHART A graphical representation of a set of microprocessor instructions.

FUSIBLE LINK ROM A read only memory into which program is permanently fixed by fusing links initally produced at every bit position. Where a link is fused a digit one is stored.

HANDSHAKE A communication principle in which a device wishing to send data, first requests permission and then waits for the receiving device to send an acknowledgement.

HEX May be used when referrring to an integrated circuit containing six separate logic elements, or when referring to hexadecimal numbers.

HEXADECIMAL A number system with radix 16. It uses the alphanumeric characters 0 to 9 and A to F.

HIGH-LEVEL LANGUAGE A computer language in which the statements represent procedures as opposed to single machine instructions.

IMMEDIATE ADDRESSING A mode of addressing in which the operand is part of the instruction.

IMPLIED (INHERENT) ADDRESSING An addressing mode in which the op-code specifies the register/accumulator address.

INDEX REGISTER A microprocessor register used for memory address modification.

INDEXED ADDRESSING A mode of addressing in which the memory address is modified by the content of the Index Register.

INSTRUCTION A group of bits used to specify a microprocessor operation.

INSTRUCTION CYCLE The cycle of fetching, decoding and executing an instruction.

INSTRUCTION EXECUTION TIME The time required to fetch, decode and execute an instruction.

INSTRUCTION SET The set of instructions that can be interpreted by the microprocessor.

INTERFACE A shared boundary.

INTERPRETER A program which resides in a computer and converts the instructions of a high-level language into machine code as the program is being executed.

INTERRUPT A microprocessor input that temporarily transfers control from the main program to a separate interrupt routine.

INTERRUPT MASKING A technique that permits the microprocessor to specify if interrupts will be accepted.

INTERRUPT ROUTINE A program that is implemented in response to an interrupt signal.

JUMP INSTRUCTION An instruction used to depart from the normal incrementing of the program counter content, by placing a new memory address value in the program counter.

LABEL A name given to an instruction or statement in a program to identify the location in memory of the object code produced from the instruction or statement.

LANGUAGE A means of conveying information. A programming language is a precise set of representations, conventions and rules for stating the sequence of operations required to perform a task.

LATCH A temporary storage element, usually a flip-flop.

LIGHT EMITTING DIODE (LED) A solid-state light source of high reliability and low power consumption commonly used as an indicator.

LOOP A sequence of instructions that a microprocessor repeats.

MACHINE CODE The language that the microprocessor can interpret directly.

MACHINE-CYCLE The basic microprocessor cycle. It is the time required to fetch data from memory or to execute a one-byte instruction.

MASK 1. A bit pattern that separates one or several bits from a group of bits.

2. A photographic plate used in integrated circuit fabrication to define the diffusion patterns.

MASKABLE INTERRUPT An interrupt that can be disabled by the system.

MEMORY An element that can store logic bits.

MEMORY ADDRESS REGISTER A register used to store the address of the addressed memory byte.

MEMORY MAP A graphical method of illustrating designated memory sections.

MICROCOMPUTER A microprocessor, memory and interface elements assembled to form a computer.

MICROINSTRUCTION One of the organised sequence of control signals that form instructions at the control level.

MICROPROCESSOR The central processing unit of a microcomputer.

MNEMONIC CODE Abbreviated descriptive titles for each machine code instruction.

MODEM A modulator/demodulator element that uses a carrier frequency in order to permit communication via a high-frequency channel.

MODIFIER A data word, used with indexed addressing mode instructions, which is added to the content of the index register to form the memory address of the operand.

MONITOR A simple operating system that permits the user to enter and run programs.

MOS DEVICES Semiconductor elements that use field effect transistors manufactured using Metal Oxide Silicon.

MULTIPLEXER An element that selects one of several inputs and places it on a time-shared output.

MULTIPROCESSING Using more than one microprocessor in a single system under integrated control.

NIBBLE A group of four bits.

NMOS N-channel Metal Oxide Silicon.

NON-DESTRUCTIVE READOUT The content of the element can be read without changing the content.

NON-MASKABLE INTERRUPT An interrupt that cannot be disabled by the system.

NON-VOLATILE MEMORY A memory that maintains its content even when the power is removed.

NO-OP An instruction that only increments the program counter.

OBJECT PROGRAM A machine-code program that is the output of an assembler.

OFFSET A number that is added to another number to form an effective address.

ONE'S COMPLEMENT A bit-by-bit complement of a binary number.

OP-CODE The part of an instruction used to specify the operation to be undertaken during the next cycle.

OVERFLOW BIT A flag is set to logic 1 if the last operation generated a two's complement overflow.

PARITY A one-bit code that is added to a word to make the total number of one bits in the word even (even parity) or odd (odd parity).

PERIPHERAL INTERFACE ADAPTER (PIA) An interface device designed to facilitate parallel communication between peripheral equipment and a microprocessor.

PMOS P-channel Metal Oxide Silicon.

POINTER A register or memory location that contains an address.

POLLING The successive examination of the state of peripherals.

PORT A device, or set of electrical connectors, which provides external access to a microcomputer for the transfer of data.

PRIORITY INTERRUPTS Interrupts that can be serviced before others, or that can interrupt other interrupt routines.

PROGRAM A sequence of instructions correctly ordered to implement a specific task.

PROGRAM COUNTER A register that holds the address of the next instruction to be executed.

PROGRAMMABLE LOGIC CONTROLLER (PLC) A general-purpose unit for machinery, plant or process control pre-programmed with routines for all normal control functions.

PROGRAMMABLE PERIPHERAL INTERFACE (PPI) An interface device designed to facilitate parallel communication between peripheral equipment and a microprocessor.

PROGRAMMABLE TIMER An element that can provide timing signals under program control.

PROGRAMMED INPUT/OUTPUT Input/output operation implemented under program control without using interrupts or DMA

PROM Programmable Read-only Memory.

PROM PROGRAMMER Equipment that can be used to program a *PROM*.

PULL Remove an operand from a stack

PUSH Put an operand on to a stack.

RAM (Random Access Memory) A memory that can be read from and written into.

REAL-TIME CLOCK An element that interrupts a microprocessor at regular time intervals.

REAL TIME OPERATION An operating mode, such as on-line control, in which a computer interacts with events as they occur.

REFRESH The process of restoring the content of a dynamic memory.

REGISTER A group of memory cells used to store words within a microprocessor.

RELATIVE ADDRESSING A mode of addressing in which the specified address in the instruction is the offset from a reference address.

RESET The action of restoring a microprocessor, or other electronic circuit, to a defined initial state.

ROM Read-only Memory.

ROM SIMULATOR A device that permits read/write memory to behave as read/only memory during system development.

ROUTINE Part of a program which is separately identifiable in that it performs a complete function.

SCRATCH-PAD MEMORY Memory locations that are used as a temporary store for data.

SECOND SOURCE A manufacturer who supplies devices originated by another manufacturer.

SEQUENTIAL OPERATIONS Operations performed one at a time, each one commencing only after the preceding one has been completed.

SHIFT REGISTER A register in which the stored data can be moved to the right or left.

SIGN BIT The most significant bit of a data word that indicates the sign of the data. Logic 0 is used to indicate a positive number and logic 1 a negative number.

SIGNAL CONDITIONING Changing a signal to make it compatible with a specific device.

SOFTWARE A set of computer programs.

SOFTWARE INTERRUPT An instruction that makes a program jump to a specific address.

SOURCE PROGRAM A computer program written in assembly or high-level language.

STACK A group of RAM memory elements that is normally accessed in a last-in, first-out manner.

STACK POINTER A register used to address the next available stack location.

START BIT A one-bit signal used to indicate the start of data transmitted asynchronously.

STATIC MEMORY A memory that does not require refreshing.

STATUS REGISTER A register whose content gives the current status of the microprocessor.

STOP BIT A one-bit signal used to indicate the end of data transmitted asynchronously.

SUBROUTINE A subprogram that can be entered from more than one place in a main program.

SYNCHRONOUS OPERATION Operating at regular intervals of time with respect to a reference time.

SYNTAX The rules of statement structure in a programming language.

TERMINAL An input/output device used to communicate with a microprocessor system.

TRI-STATE Logic outputs with three possible output levels, low, high and high impedance.

TTL Transistor-Transistor Logic. This is a very popular bipolar technology used in integrated circuits.

TTL-COMPATIBLE DEVICES These use voltage and current levels within the TTL range and do not need level-shifting for interfacing to TTL devices.

TWO'S COMPLEMENT The one's complement of a binary number plus one.

UNIVERSAL SYNCHRONOUS/ASYNCHRONOUS RECEIVER/TRANSMITTER (USART) A program controlled device for serial input/output communication.

VECTORED INTERRUPT An interrupt that provides the microprocessor with an identification code that may be used to transfer control to a service (interrupt) routine.

VOLATILE MEMORY A memory that loses its content when the power is removed.

WIRED-OR CONNECTION A connection that can be used for connecting several devices to a single bus or device input.

WORD The group of bits that a microprocessor can manipulate.

WORD LENGTH The number of bits in a microprocessor word.

APPENDIX A

BINARY ARITHMETIC, LOGIC, SYMBOLS AND CIRCUITS

A.1 Binary Arithmetic

The binary numbering system employs only two digit symbols, zero and one, so that numbers with the base, or radix, of two are made up of digits whose values increase in powers of two. The binary equivalents to the decimal numbers one to fifteen are shown in Table A.1 together with the corresponding hexadecimal characters. As can be seen, four binary digits, or bits, can be represented by a single hexadecimal character and this is why the latter notation is found more convenient to use when programming microprocessors.

Table A.1 Equivalent decimal, binary and hexadecimal numbers

Decimal Numbers	Binary numbers 8 4 2 1 (2^3 2^2 2^1 2^0) (see note 1) (see note 2)	Hexadecimal characters
0	0 0 0 0	0
1	0 0 0 1	1
2	0 0 1 0	2
3	0 0 1 1	3
4	0 1 0 0	4
5	0 1 0 1	5
6	0 1 1 0	6
7	0 1 1 1	7
8	1 0 0 0	8
9	1 0 0 1	9
10	1 0 1 0	A
11	1 0 1 1	B
12	1 1 0 0	C
13	1 1 0 1	D
14	1 1 1 0	E
15	1 1 1 1	F

Note 1. Decimal values of each binary digit position.
Note 2. Powers of two for each binary digit position.

A.1.1 Addition:

As with any other number system when the sum of the digits in a particular position exceeds the value of the highest symbol used (in this case 1) a carry to the next more significant position is generated. Thus:

$0+0=0,$
$0+1=1,$
$1+0=1,$
$1+1=0$ with carry.

And when there is a carry from the less significant position:

$0+0+1=1,$
$0+1+1=0$ with carry,
$1+0+1=0$ with carry,
$1+1+1=1$ with carry.

For example:

```
   14          1 1 1 0
 + 7         + 0 1 1 1
   --        -------
   21        1 0 1 0 1
    *          * * *      *carry one.
```

A.1.2 Subtraction:

When the digit being subtracted exceeds that from which it is to be taken borrowing from the next more significant position must occur. Thus:

$0-0=0,$
$0-1=1$ with borrow,
$1-0=1,$
$1-1=0.$

And when there is a borrow to the less significant position:

$0-0-1=1$ with borrow,
$0-1-1=0$ with borrow,
$1-0-1=0,$
$1-1-1=1$ with borrow.

For example:

```
   14          1 1 1 0
 - 7         - 0 1 1 1
   --        -------
   7         0 1 1 1
    *            * * *      *borrow one.
```

An alternative method of binary subtraction is employed by microprocessors because it simplifies the circuit requirements. Each digit of the number to be subtracted is inverted (zeros become ones and ones become zeros) and the result (known as the ones complement) is added to the other number. If there is a carry from the most significant bit (MSB) it is added as a carry into the least significant bit (LSB).

Using the previous example:

```
   14                          1 1 1 0
 - 7   0 1 1 1   inverted      1 0 0 0   +
                               -------
                               0 1 1 0
                 carry one     *
                 add carry to LSB  0 1 1 1   i.e. 7
                                   -------
```

A.1.3 Multiplication:

Binary numbers are multiplied by a shift and add process like long multiplication.

For example:

```
10×7
10          1 0 1 0   ×0 1 1 1   7
                  1 0 1 0                 *   no shift
              1 0 1 0 0                   *   one shift
              1 1 1 1 0
          +1 0 1 0 0 0                    *   two shifts
        1 0 0 0 1 1 0
        64      +4+2      =70
```

The product of two 4-bit numbers could be up to an 8-bit number.

A.1.4 Division:

Binary division is performed by a shift and subtract process like long division. If the result of a subtraction is positive the relevant digit of the quotient is one, but if the subtraction produces a negative result the digit is zero and the divisor must be added back. A negative result of subtraction is indicated by a one as the most significant bit.

For example 70 divided by 7:

							0	1	0	1	0		10
	7	0	1	1	1	1	0	0	0	1	1	0	70
					−0	1	1	1					
negative					1	1	0	1					
therefore					+0	1	1	1					
						1	0	0	0				
					−	0	1	1	1				
positive						0	0	0	1	1			
					−		0	1	1	1			
negative							1	1	0	0			
therefore					+		0	1	1	1			
							0	0	1	1	1		
					−			0	1	1	1		
positive								0	0	0	0	0	
					−				0	1	1	1	
negative									1	0	0	1	
therefore					+				0	1	1	1	
Remainder									0	0	0	0	

A.2 Logical Operations

Strictly speaking logic is a discipline of philosophy dealing with the truth or falsehood of statements and combinations of statements. However, machinery control operations can be defined in statements such as:

(a) The machine is to start only if the operator presses the start button.

(b) The machine is to start only if the interlock conditions (e.g. lubricating oil pressure and temperature) are correct.

Therefore:

(c) The machine is to start only if the operator presses the start button AND the interlock conditions are correct.

This is a logical AND function and an electronic element to impliment it is known as an AND-gate; the interlock signal in the above example acts as though it were opening or closing a gate for the start signal to pass through. Truth and falsehood are two mutually exclusive conditions with no middle ground and are represented as logic level one and logic level zero. The output condition of a logic element for any combination of input conditions is expressed in the form of a *truth table.* In microprocessor systems logic level one is represented by approximately five volts and logic level zero by approximately zero volts. When the more positive voltage is selected to be logic level one the system is termed *positive logic.*

A.2.1 Logic Functions:

The truth tables for a number of basic logic functions are given in Fig. A.1 together with graphical symbols in accordance with British Standard 3939: Section 21 (equivalent to IEC Publication 117-15) and American National Standards Institute Y32.14-1973 (adopted as IEEE Standard 91-1973). These symbols were primarily intended for use on design drawings of system hardware, but may also be used on schematic diagrams of system software.

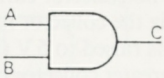
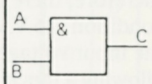
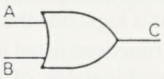
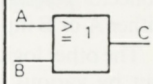
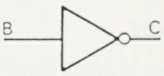
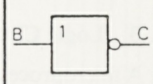
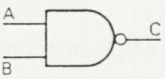
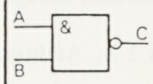
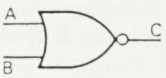
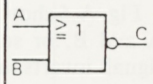
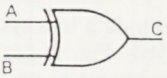
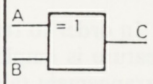
				Symbols	
Function	A	B	C	ANSI	BS
AND	0	0	0		
	0	1	0		
	1	0	0		
	1	1	1		
OR	0	0	0		
	0	1	1		
	1	0	1		
	1	1	1		
NOT (Inversion)		0	1		
		1	0		
NAND	0	0	1		
	0	1	1		
	1	0	1		
	1	1	0		
NOR	0	0	1		
	0	1	0		
	1	0	0		
	1	1	0		
Exclusive OR	0	0	0		
	0	1	1		
	1	0	1		
	1	1	0		

Fig. A.1 Logic Functions and Symbols

For an AND function the output is one when input A AND input B are one.

For an OR function the output is one when input A OR input B is one.

For a NOT function, or INVERSION, the output is one when the input is NOT one.

For a NAND (NOT-AND) function the output is NOT one when input A AND input B are one.

For a NOR (NOT-OR) function the output is NOT one when input A OR input B is one.

For an EXCLUSIVE-OR function the output is one when input A OR input B is one but not both.

A.2.2 Electronic Logic Gates:

Logic functions can be implemented by various technologies (e.g. electrical relays or pneumatic systems) which are selected by a designer as most appropriate to a particular application. For speed and compactness nothing compares with electronic techniques.

The active elements in electronic logic gates are transistors. Fig. A.2 shows a simplified arrangement for a NOT gate or inverter. Transistors are current amplifying devices, the collector current is a multiple (the 'gain') times the base current. When the input voltage to the base is 0 V (logic zero) no base current can flow, therefore, there is no collector current. The output voltage in this condition is 5 V via the collector resistor R_c, i.e. logic one. When the input voltage is raised to 5 V (logic one) a base current flows allowing a much greater collector current to pass. As the collector current is limited by R_c, the collector voltage (and hence the output) output) falls to less than 0,5 V, i.e. logic zero.

Two similar circuits can be combined together with a common collector resistor to make a NOR gate as shown in Fig. A.3. If either A or B input is logic one the output C will be logic zero.

The other logic functions listed in Fig. A.1 could also be carried out by various combinations of the same basic circuit but, in practice, integrated circuit logic gates employ more complex arrangements with devices such as multi-emitter transistors.

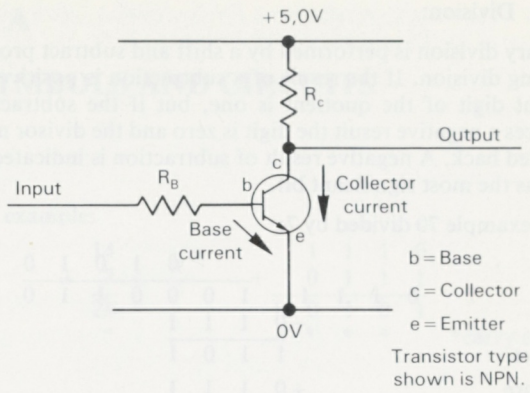


Fig. A.2 Simplified Transistor NOT-Gate

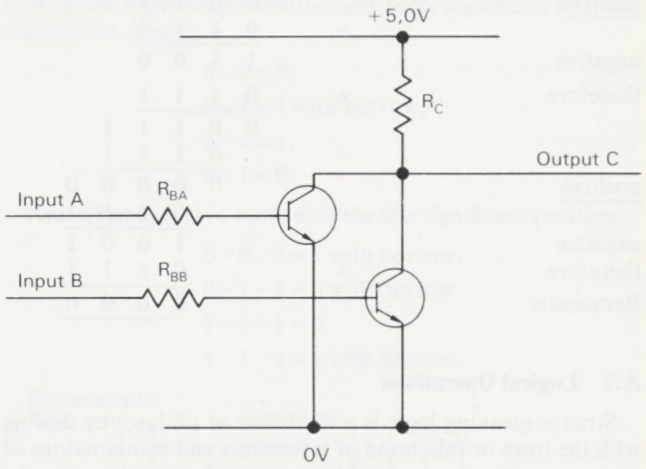


Fig. A.3 Simplified Transistor NOR-Gate

A.3 Logic Circuits

A microprocessor is made up of several thousand logic gates of the basic types described above. The arrangements for AND, OR, EXCLUSIVE-OR and INVERSION functions in a processor are straightforward, but the circuits for binary addition, subtraction and data storage are rather more involved.

A.3.1 Addition and Subtraction:

Fig. A.4(a) shows the logic circuit of a half adder capable of adding two signals together to produce sum and carry outputs. In order to be able to handle the carry from a less significant bit as well, it is necessary to use a full adder as shown in Fig. A.4(b).

Fig. A.5 shows a configuration for adding two 8-bit numbers, A and B, or subtracting B from A. The subtract command signal inverts all the digits of number B to give its ones complement, and also enables the necessary 'end-around carry' from MSB to LSB.

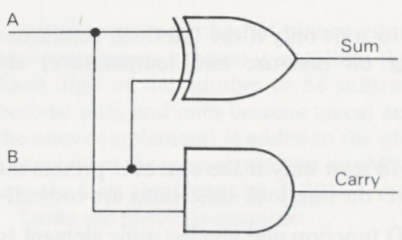
A.3.2 Data Storage:

In order to retain data in a system a circuit with a self-hold feature is employed. Fig. A.6(a) shows a set/reset bi-stable arrangement (also known as an R-S flip-flop) comprising two NAND gates. The truth table for such a device has now to take account of the sequence in which the input conditions have occurred and this is indicated with a subscript zero to show that the output has been unchanged by that particular combination of input signals. The storing state is with both inputs one. If the S input becomes zero the Q output will become one and stay in that state after the S input has been returned to one. The Q output can be reset to zero by a zero on input R.

In a microprocessor it is necessary to control the transfer and storage of data by timed pulses. Fig. A.6(b) shows a simplified version of the circuit of a D-type flip-flop. When the clock input is raised to one the data on the D input is transferred the Q output. When the clock input returns to zero Q remains unchanged and is not affected by any changes of the D input.

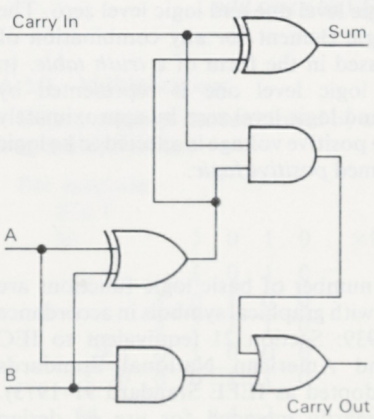
To store an 8-bit byte of information eight D-Type flip-flops are required. This constitutes an 8-bit register. Fig. A.7 shows such a register as part of a microprocessor memory. For this purpose it is necessary to decode the address of the register and also supply a signal to indicate whether a read or write operation (data out of or into memory) is required. Because all the registers have their outputs connected to the same data bus connections, they are all provided with output circuits, described as *tri-state,* which are capable of being disabled by putting them into a high impedance state.

A random access memory chip for a microprocessor system contains several thousand registers similar to the arrangement shown.



A	B	S	C
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Fig. A.4(a) Half Adder Circuit



A	B	CI	S	CO
0	0	0	0	0
0	1	0	1	0
1	0	0	1	0
1	1	0	0	1
0	0	1	1	0
0	1	1	0	1
1	0	1	0	1
1	1	1	1	1

Fig. A.4(b) Full Adder Circuit

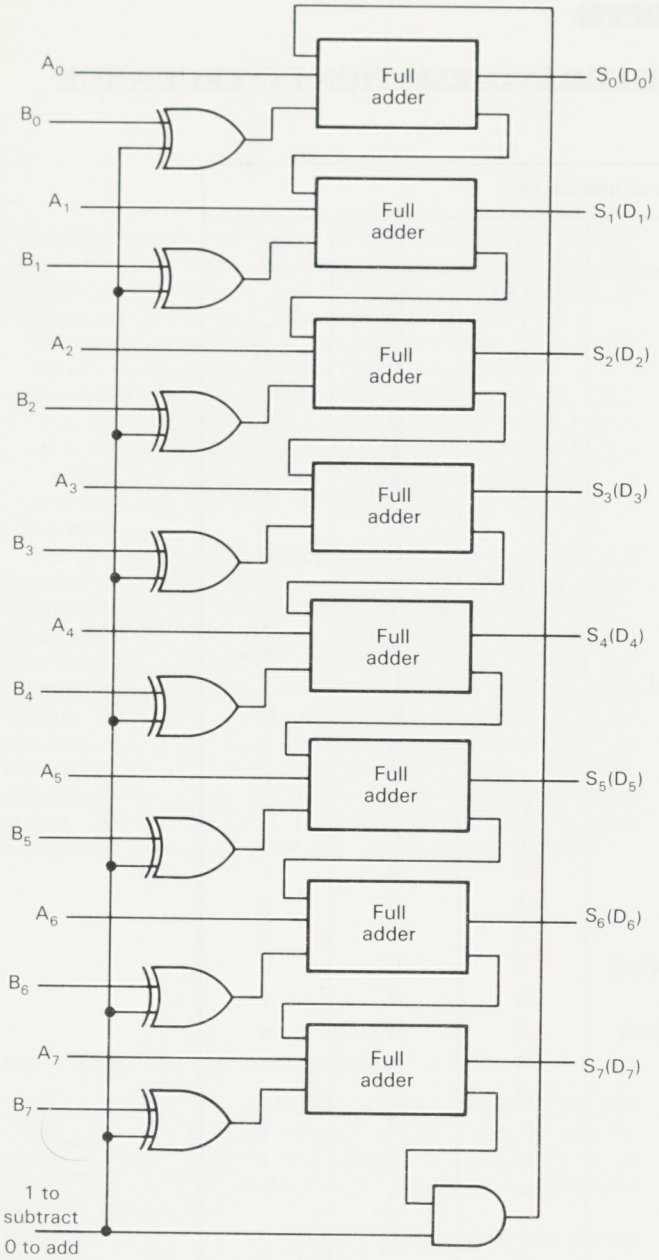
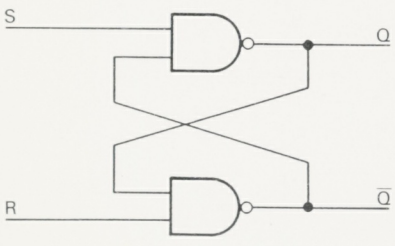
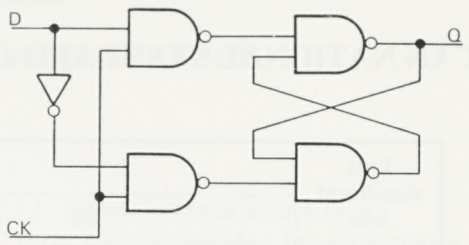


Fig. A.5 8-Bit Adder/Subtractor



S	R	Q	$\overline{Q}$
0	0	1	1
0	1	1	0
1	0	0	1
1	1	Q_0	$\overline{Q}_0$

Fig. A.6(a) Bistable Circuit



D	CK	Q
0	0	Q_0
1	0	Q_0
0	1	0
1	1	1

Fig. A.6(b) Simplified D-Type Flip-Flop

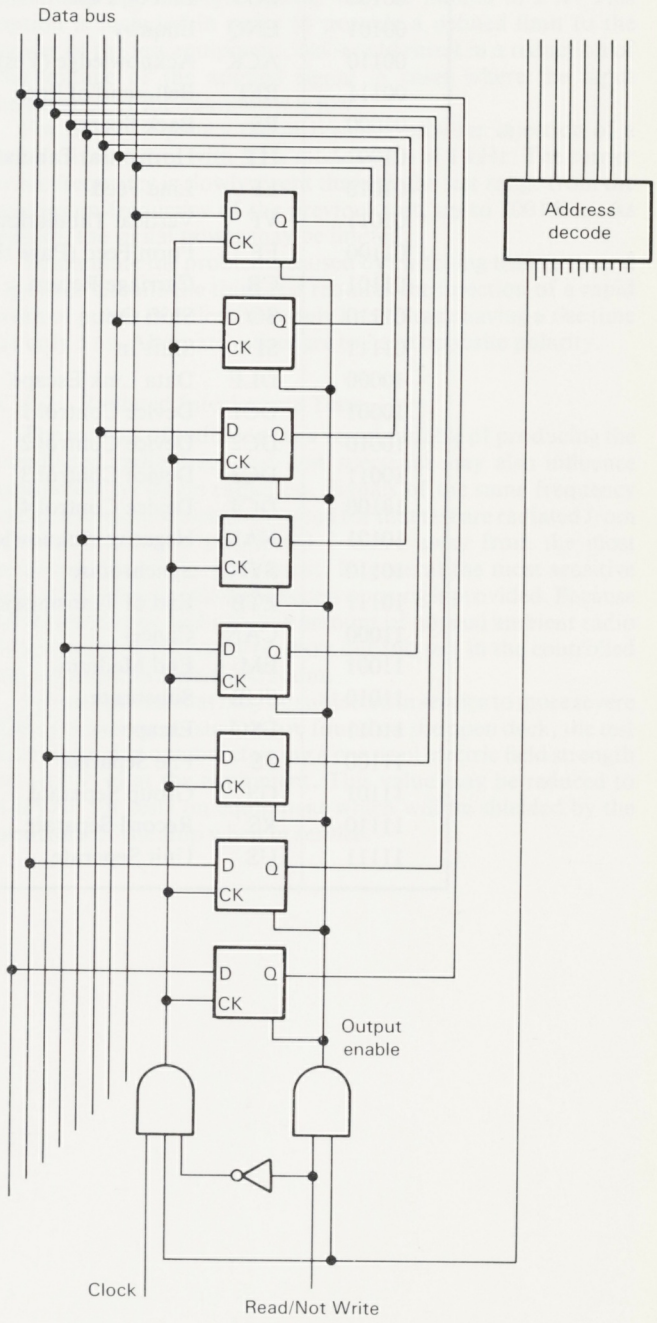


Fig. A.7 8-Bit Memory Register

APPENDIX B

AMERICAN NATIONAL STANDARD CODE FOR INFORMATION INTERCHANGE

Less significant bits	More significant bits				
	00		01	10	11
00000	NUL	No signal	SPACE	@	.
00001	SOH	Start of Header	!	A	a
00010	STX	Start of Text	"	B	b
00011	ETX	End of Text	#	C	c
00100	EOT	End of Tape	$	D	d
00101	ENQ	Enquiry	%	E	e
00110	ACK	Acknowledge (Yes)	&	F	f
00111	BEL	Bell, (end of line)	'	G	g
01000	BS	Back Space	(	H	h
01001	HT	Horizontal Tabulation	)	I	i
01010	LF	Line Feed	*	J	j
01011	VF	Vertical Tabulation	+	K	k
01100	FF	Form Feed (Page throw)	,	L	l
01101	CR	Carriage Return	-	M	m
01110	SO	Shift Out	.	N	n
01111	SI	Shift In	/	O	o
10000	DLE	Data Link Escape	Ø	P	p
10001	DC1	Device Control 1	1	Q	q
10010	DC2	Device Control 2	2	R	r
10011	DC3	Device Control 3	3	S	s
10100	DC4	Device Control 4	4	T	t
10101	NAK	Negative Acknowledge (No)	5	U	u
10110	SYN	Synchronise	6	V	v
10111	ETB	End of Transmission Block	7	W	w
11000	CAN	Cancel	8	X	x
11001	EM	End Medium	9	Y	y
11010	SUB	Substitute	:	Z	z
11011	ESC	Escape	;	[	{
11100	FS	File Separate	<	\	|
11101	GS	Group Separate	=	]	}
11110	RS	Record Separate	>	^	~
11111	US	Unit Separate	?	—	DELETE

APPENDIX C

ELECTROMAGNETIC INTERFERENCE

Electromagnetic interference (EMI) is becoming an increasing problem on board merchant vessels as the power and frequency spectrum of sources grows and the types of equipment installed tends to be of increasing sensitivity.

Microprocessor systems come within the latter category due to the very low energy content of their internal signals.

Interference sources include radio communication transmitters of increasing power, radar installations and power circuits, especially those employing thyristor control. As well as the effects of a ship's own installations, EMI may be experienced due to those of other ships or shore based equipment.

The problem has been recognised for some time in naval vessels due to the quantity and sophistication of their electronic equipment and its close-packed installations. Because of this, naval specifications relating to electromagnetic compatibility have been in existence for a number of years. In 1977 the International Electrotechnical Commission produced its publication 533 which is a recommended code of practice for merchant vessels entitled 'Electromagnetic Compatibility of Electrical and Electronic Installations in Ships'. This categorises various sources of EMI and susceptible equipment and makes recommendations regarding the separation and screening of cables associated with each type of equipment.

C.1 Equipment Susceptibility Testing

After consideration of the likely sources of EMI and their frequencies, the following series of tests has been devised for inclusion in the Society's requirements for equipment Type Approval at the next revision. They will only be applicable to electronic equipment.

During each test the equipment is to be operational and no detectable maloperation should occur.

C.1.1 Conducted Interference Tests:

Three tests are specified for susceptibility to interference conducted to the equipment by its own power supply connections.

The first requires the superimposition of a constant voltage sinusoidal signal of 1,0 V r.m.s. onto the supply lines. This signal is slowly swept through the audio frequency range. The maximum applied signal power may be limited to 2 W. This option is included in order to provide a defined limit to the power of the test equipment, but would result in a reduction of the voltage of the applied signal in cases where the input impedance of the equipment is low.

For radio frequency the second test requires injection of a 1,0 V carrier wave with 30% modulation of 1 kHz. The carrier wave frequency is slowly swept through the test range from the maximum frequency of the previous test, up to 200 MHz. As before, the signal power may be limited.

To simulate the problems caused by switching transients and thyristor circuits the third test requires the injection of a rapid train of pulses of twice the supply line voltage having a rise time of only 5 ns. Alternate pulses are to have opposite polarity.

C.1.2 Radiated Interference Tests:

The sources of radiation on a vessel capable of producing the conducted radio frequency test spectrum may also influence equipment by direct radiation. Signals of the same frequency range and modulation as required for that test are radiated from a suitable antenna positioned 1 metre away from the most sensitive side of the equipment. In general the most sensitive side will be that in which the access opening is provided. Because of the unknown and variable amount of normal ambient radio frequency it is necessary to carry out this test in the controlled environment of a shielded room.

For equipment that may be subjected in service to more severe EMI environments such as are found on the open deck, the test is to be carried out maintaining a constant electric field strength of 10,0 V/m at the equipment. This value may be reduced to 1,0 V/m for tests on equipment which will be shielded by the structure of the ship when in service.

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Lloyd's Register Technical Association

FUTURE ASPECTS OF MARINE TECHNOLOGY

Professor R. V. THOMPSON

Guest Lecture Session 1984-85

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The lecture given by Professor Thompson to the Lloyd's Register Technical Association on Wednesday 13th, February 1985, was similar in content to his previous lecture to the Institution of Mechanical Engineers on the 23rd, January 1985. This latter lecture formed the fifty-seventh Thomas Lowe Gray Lecture and is reproduced here in the Lloyd's Register Technical Association transactions from the procedings of the Institution of Mechanical Engineers by permission of the Council of the Institution of Mechanical Engineers.

The opinions expressed and statements made in this paper are those of the author. No discussion on this lecture will be published.

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Fifty-seventh Thomas Lowe Gray Lecture

Marine technology—present and future

Professor R V Thompson, BSc, MEng, PhD, CEng, FIMarE, FIMechE, FRSA
School of Marine Technology, The University of Newcastle upon Tyne

The paper attempts to present a scenario of the change in energy sources and availability occurring in the world today and its effect on trading patterns. As a result of this analysis, an impression of shipping requirements and hence potential demand is developed. Associated required engineering developments are postulated both in the area of traditional sea-going trade and also offshore and subsea systems.

The progress of specific related research projects and their expected contributions to technological expertise and operational availability is presented.

The precarious position of the UK industry versus the rest of the world is highlighted, and a plea made for a technological lead recovery.

1 FUEL AVAILABILITY

The forecasting of future energy supplies is at best a precarious occupation, particularly if the vagaries of common human activities are ignored. Even the best techno-economic evaluation based on historical trends, material growth, known supplies, etc. may be totally invalidated by local wars, retrenchment or sheer political belligerence.

Fortunately, the objective of this analysis is simply to define the type of fuel which will be available to the Marine industry in the foreseeable future, and also the effect of any potential energy trading changes which would or could affect the demand for ships, offshore rigs and related technological advance.

Between 1974 and 1980 the cost of oil increased by 300 per cent while at the same time the cost of living increased by 230 per cent and 160 per cent in the UK and USA respectively. Since then a sense of reality has prevailed with energy prices at worst bottoming out and at best falling in real terms. The 'bottom line' is that all fossil related energy sources are finite, and their relative finality obviously has a direct effect on marine transportation, operation and engineering advances. A brief review follows.

1.1 Primary energy trends

Although energy exists in myriad forms, that which is of interest here is primary energy, *viz.* oil, coal and gas. Other forms of power generation, although important in themselves, have little bearing on the sea transportation scenario and are ignored here.

The second oil crisis ensured that the original warning was rammed home and in consequence global energy consumption has continued to fall since 1979, although the rate of change has slackened appreciably since 1982. Energy conservation has become the norm in the Western industrialized nations, with combustion improvements in some areas being in excess of 70 per cent of values generally acceptable ten years ago by the automobile product. Furthermore, oil has been located in substantial quantities around the world and usually well away from traditional areas of production, *viz.* North Sea and Mexico. Additional vast resources of shale oil and tar sands are being developed as the 'energy unit' approaches their economic production levels. The production of oil from coal is also warranting serious research to maximize the benefits of necessity demonstrated by the South Africans and Germans over past decades. What, therefore, is a reasonable estimate of availability of these primary energy products and what has and will be the effect on sea transportion, and hence the intermediate and long-term engineering requirements of the world's most economic means of resource renewal? Each element is considered in isolation below.

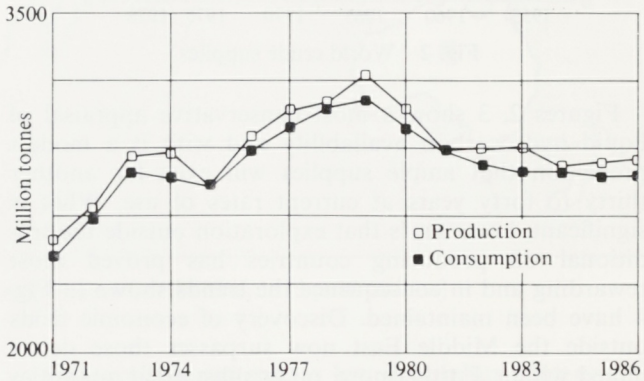


Fig. 1 World oil projected comparison

1.2 Oil

Figure 1 shows the variation in oil consumption and production on a 'world' basis. The prime conclusion to be drawn from this figure is that energy conservation in the so-called industrialized nations has been most successful, particularly if it be appreciated that Eastern Europe both increased production and consumption during the period shown. The general assumption is that the Western world energy economy scenario has bottomed out and that some modest increase in requirements may be manifest in the next few years, particularly if confidence returns in guarantee of supply.

This lecture was presented at an Ordinary Meeting held in London on 23 January 1985. The MS was received on 11 December 1984.

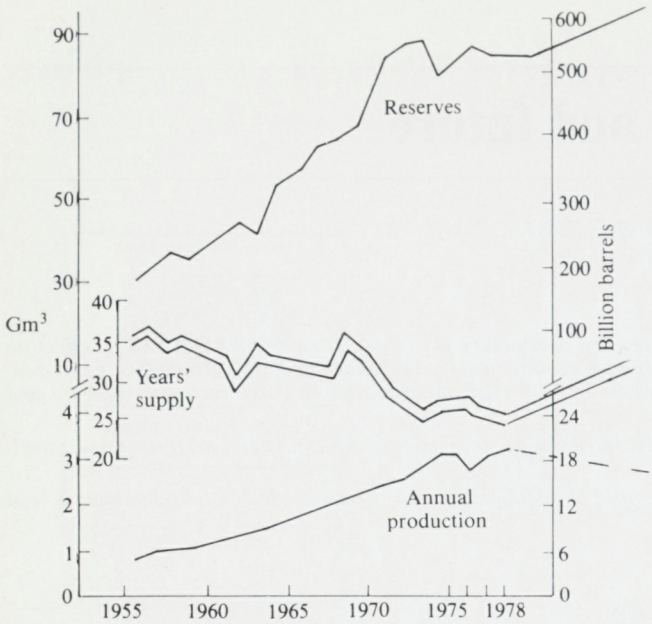


Fig. 2 World crude supplies

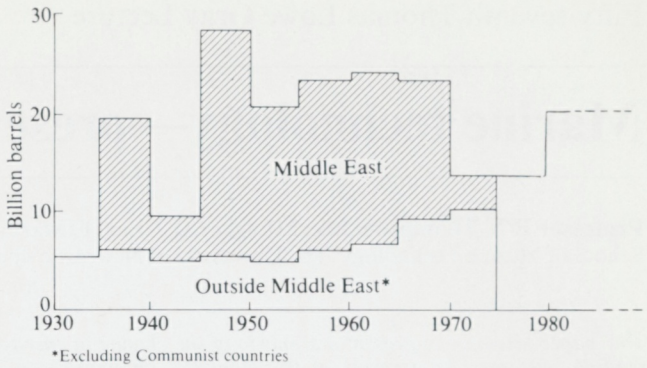


Fig. 4 Comparison of oil discovery rates (five year average)

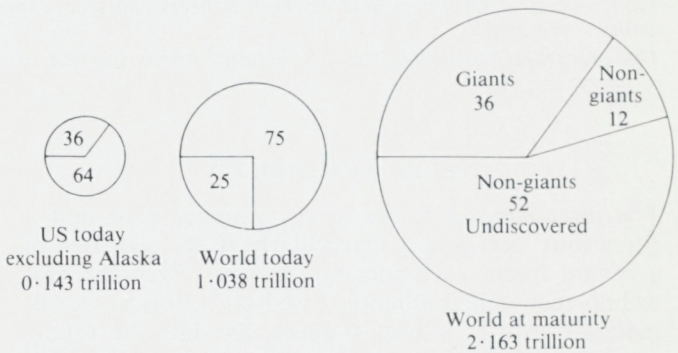


Fig. 5 Economic base predictions from comparison of giant fields

Figures 2, 3 show a most conservative appraisal of liquid hydrocarbon availability and with it a modest prediction that ample supplies will exist for another thirty to forty years at current rates of use. What is significant, however, is that exploration outside the traditional oil producing countries has proved most rewarding and in consequence the trends shown in Fig. 4 have been maintained. Discovery of economic fields outside the Middle East now surpasses those determined within. Furthermore, oil in substantial quantities has been found in relatively stable areas of the globe, permitting in turn predictable availability and hence use.

More plausible are the extrapolated data shown in Fig. 5. For example, it is postulated that intense exploration results in oil being produced in the ratio of 'giant' to other fields of 36–64 per cent whereas in the world overall, 75 per cent of supply is obtained from 'giant' fields only. The extension of intensive exploration worldwide in combination with the development of better recovery technology leads to the theory that possible world oil recovery may be three times as large as that accepted today. Assuming that world energy related growth rate increases at 3.5 per cent per annum, associated production would tend to peak around the year 2030 at technically feasible rates of recovery. Commercial and, more significantly, political considerations should extend this date considerably, particularly if world economic growth is inhibited severely.

The above scenario neglects the impact which oil shale and tar sands could have on the overall situation. The former is a sedimentary rock which is fully impregnated with a solidified hydrocarbon wax, kerogen, which may be decomposed at elevated temperatures to form a refinable oil based product.

World reserves of oil shale are estimated to be in excess of 300 billion toe (tonnes oil equivalent) distributed as indicated in Fig. 6 with by far the largest deposits being found in North America. These deposits are

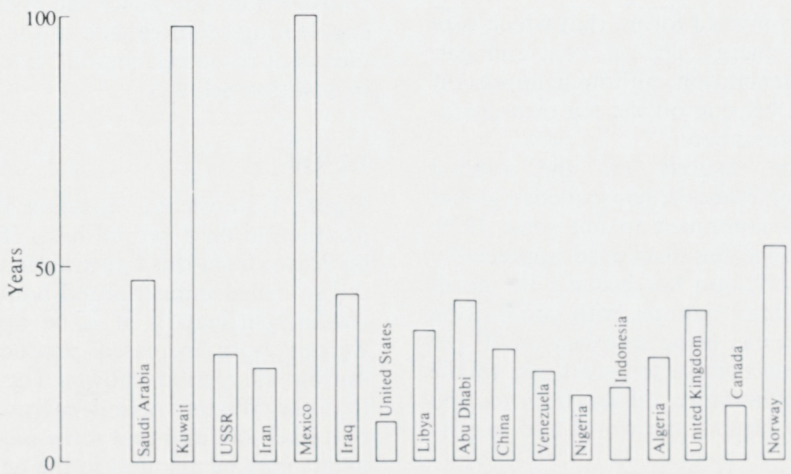


Fig. 3 Years of proven oil reserves remaining at current production rates

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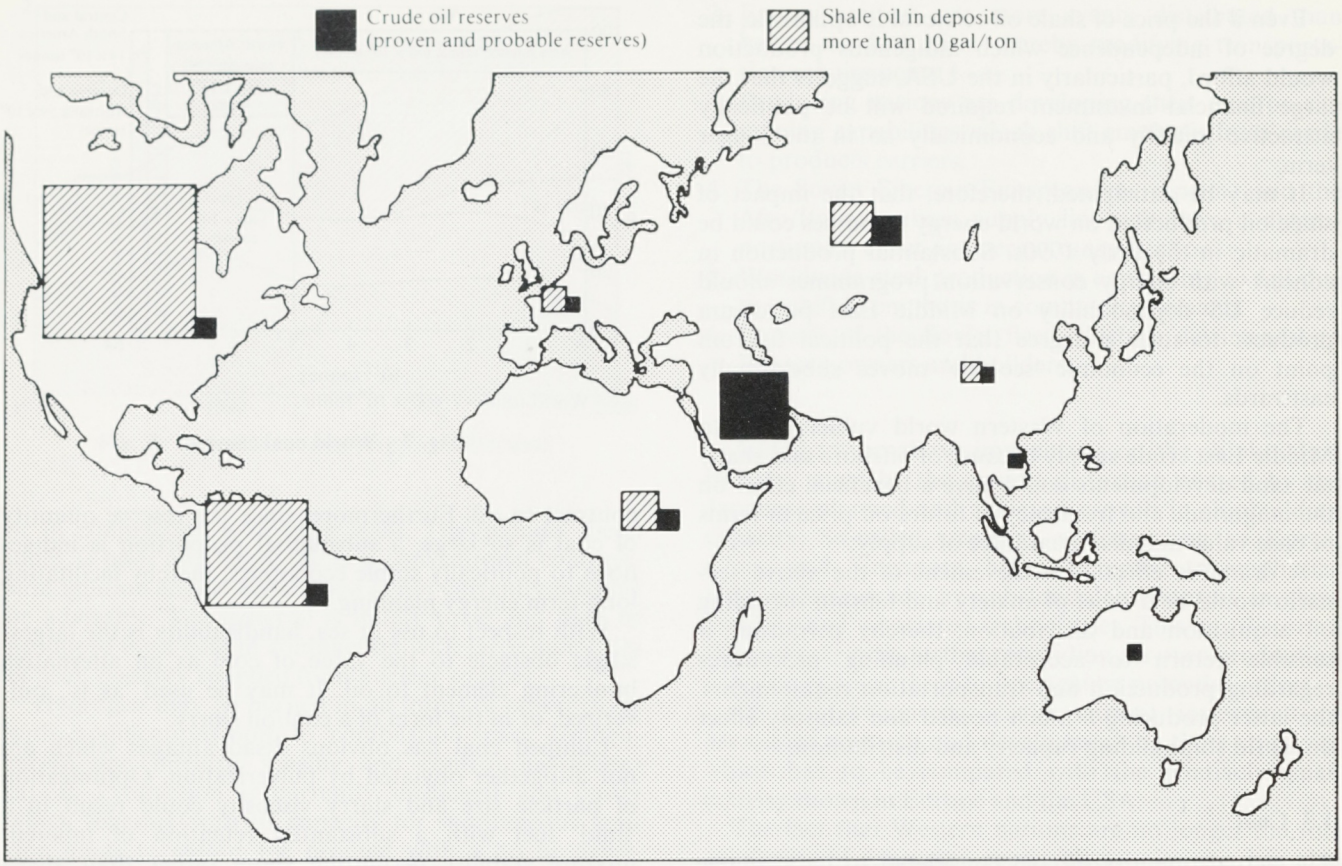


Fig. 6 Crude oil and shale oil reserves [*World Oil, Oil and Gas Journal*, 1973 publications]

capable of producing 100 litres/tonne of rock and are relatively accessible. Production is labour intensive, requires huge quantities of water and demands substantial development of explosive production techniques to permit large scale economic recovery. Table 1 provides a typical analysis of the oil produced from shale deposits.

Tar sands are found extensively in Canada and are extremely rich in bitumen. Although total reserves in place are estimated at 100 billion toe, ecological problems will probably limit production to 1.6×10^4 Mtoe.

The resulting material is low in sulphur content and has a typical specific gravity of 0.84.

The above fuels demonstrate a viscosity of 120 seconds at 60–65°C.

Oil produced in this manner averages $20 in total manufacturing cost and in consequence has a profit margin potential approaching half that experienced by relatively expensive North Sea products. However, it is sold at competitive prices and as production techniques improve and demand increases this energy source will fill the potential void left by conventional crude.

Table 1 Properties of synthetic crude oil

COED process	
Typical values only: considerable variation is likely depending on coal source	
Specific gravity	0.900
Viscosity at 38°C	3.4 cSt (34 second Redwood 1)
Flash point (closed cup)	8°C
Pour point	2°C
GCV	44 000 kJ/kg
Sulphur	0.0001% by weight
Ash	0.005% weight
Cetane rating	Approx. zero
SRC process	
Specific gravity: varies from light to heavy depending on the extent of final hydrogenation process	
GCV	37 000 kJ/kg (constant regardless of the source of the coal feedstock)
Sulphur	0.8% weight
Ash	0.1% weight

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Even if the price of shale oil retrieval is optimistic, the degree of independence which indigenous production would afford, particularly in the USA, suggests that the large financial investment required will be politically attractive initially and economically so in the longer term.

It may be anticipated, therefore, that the impact of shale oil production on world energy resources could be dramatic in the early 1990s. Substantial production in concert with energy conservation programmes should reduce US dependability on Middle East petroleum products to such a degree that the political fulcrum point on the economic 'see-saw' moves substantially eastwards.

The moderation of Western world vulnerability to Middle East crude supply because of offshore and shale/tar sand developments could have a beneficial effect on the magnitude and frequency of future oil price in terms of base value and also guarantee of supply.

A dramatic effect of achievement of the above scenario would be a relief of anxiety and tension regarding oil acquisition and distribution, thereby permitting a sensible return to acceptable planning procedures regarding production and transportation requirements, the latter producing a much needed and salutory effect on world shipbuilding capacity and distribution.

1.3 Coal

The actual quantity of coal considered to be available today varies with the source of the assessment. However, it is generally agreed that world coal in place in vast (Fig. 7). Reserves known to be economically viable in terms of recovery exceed availability of crude in the ratio of four to one, i.e. approximately 0.4×10^{12} Mtoe. Total reserves, not necessarily recoverable due to ecological and related pressures, probably exceed 1.74×10^{12} Mtoe, and are distributed as shown in Table 2. The ratio of economically recoverable to total available will probably increase with demand, although in any event currently available supplies are sufficient to meet total world energy demand for the next 100 to 300 years depending upon forecast of world growth and capacity to retrieve.

Table 2 Ultimate world coal reserves (Mtoe)

Africa	9 530
Asia	179 210
Europe	98 245
USSR	924 000
N America	490 600
S America	5 335
Oceania	32 300
Total	**1 739 220**

Currently coal is the prime competitor to oil and obviously, in many applications, must be considered as a viable alternative. In spite of the overall general reduction in oil price, coal has still maintained a competitive edge. This is probably due not only to its general prolification, but also its relatively broad distribution and in consequence many producing economies are in competition with each other in relative

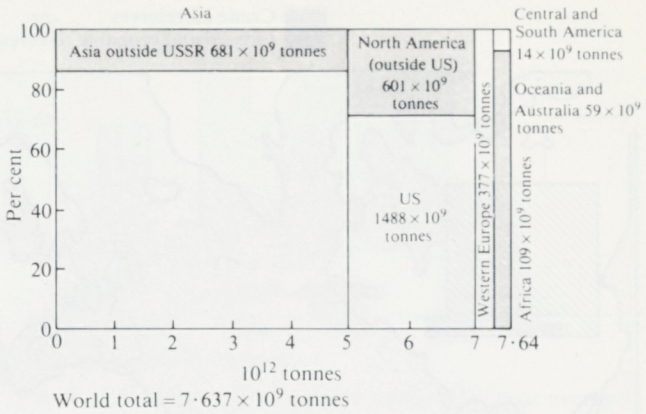


Fig. 7 World coal reserves

contrast to oil. Furthermore, since the reserve quantity of coal is so large, a substantial proportion is indigenous to politically stable economies, thereby facilitating long-term energy planning.

With respect to use at sea, handleability is the largest single obstacle to the value of coal as an alternative bunkering element to oil. It may be used 'as is', pulverized, or in the form of a coal/oil slurry.

Lumped coal has obvious disadvantages which are not altogether obviated by pulverization. Optimization of particle size and slurry viscosity could result in a 'fluid' fuel with a substantial retention of inherent mixture stability permitting shore rather than at-sea preparation.

The use of coal at sea in either the solid or pulverized state except for certain specific applications, e.g. Far East coal trade, is most unlikely due to its relatively low heating value (30 000 kJ/kg) necessitating a 30–50 per cent increase in bunkering weight or 100 per cent increase in volume. Aesthetic difficulties also apply, particularly the need for implementation of stringent fire safety legislation at the design stage.

1.4 Other fuels

Interest in a gross sense is being shown in the development of alternative fuels for power generation; however their impact on marine propulsion technology, with the exception of specialized application, is unlikely to be of definitive proportions.

Natural gas is apparently in abundance, and grandiose schemes are currently either in operation or under development for its use, for example, the trans-Siberian pipeline scheme to Europe, the sub-Mediterranean supply to Italy and the growth of domestic usage in the UK, Holland and particularly Japan which intends tripling its use in the next two years. This obviously will have a knock-on effect on the sea transportation scenario.

Apart from liquefied natural gas (LNG) which is too valuable a commodity to use in other than specialized applications at sea, methanol and hydrogen show significant promise but require substantial technological advance in production techniques to reach viability. The former has a calorific value of 20 000 kJ/kg and a specific volume double that of heavy fuel oil. It may be handled with equanimity as with conventional hydrocarbons and can be burned in boilers either on its own

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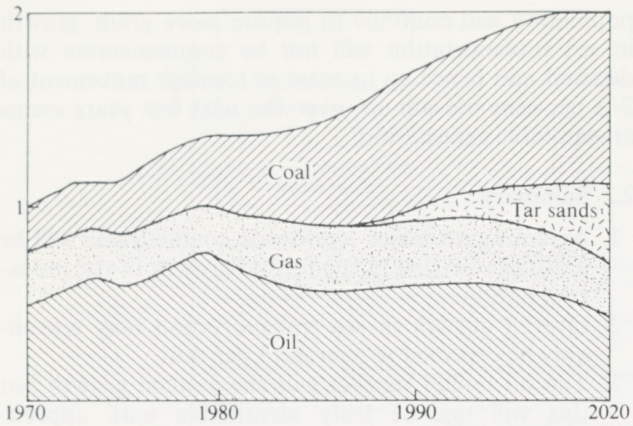


Fig. 8 Possible future energy contributions

or in conjunction with other fuels. The 'pseudo' diesel index is poor and hence use in a conventional compression ignition engine installation is not currently possible or advisable. The material is mildly toxic and may be produced from coal in conjunction with large quantities of heat, possibly supplied from nuclear sources.

Hydrogen may be burned in all forms of power plant with modifications both to 'combustion space' configuration and intrinsic sensing and control instrumentation. Production is currently inefficient and costly which together with its capacity for spontaneous ignition tends to colour the product with a 'to be developed' syndrome, apropos general use in the marine field.

Ultimately demand will exceed permissible supply—even the UK is projected to require assistance from the Norwegian sector of the North Sea, and hence emphasis will gradually revert to other energy sources. Fig. 8 shows the possible scenario over the next 35 years or so.

2 MARINE TRANSPORTATION

The previous analysis indicates that liquid carbon will form the basis of power generation in the predictable future with alternative liquid fuels gradually assuming an increasingly significant role. The difficulty is to predict whether there will be a demand for ships and associated equipment of sufficient magnitude to encourage investment and hence technological growth, particularly in Western Europe.

Although the world manufacturing nations are said to be in a state of current recession, recession in modern times is symptomatic with a decline in the rate of growth as opposed to a linearized increase in production or a holding of a stable volume position. The so-called depressed market is primarily due to world over-production in almost every conceivable technological area, and also the capacity for 'reawakening' dynasties to develop their own industries at a rate which outstrips traditional 'value added' centres.

The associated problems may be defined briefly as follows:

1. The increase in fuel price has been counter productive as the Western world has both developed alternative sources of energy and effective methods of conservation.
2. Energy sources are more evenly distributed than before the fuel crisis, thereby modifying transportation requirements.
3. Producing nations are developing their own on-site refining capabilities which shift emphasis from crude to products carriers.
4. The Soviet Siberian/European gas pipeline and the Afro/Italian subsea supply line will have a disproportionate effect on energy transportation.
5. Worldwide steel production is continuing to fall due to a shift in emphasis in commodity demand.
6. Growth of the Soviet fleet which is detrimental to Western owners and builders.

Added to the above impositions on the shipbuilding industry must be the market distortion caused by the Japanese planned and achieved growth in shipbuilding capacity. So-called emerging nations, such as Korea, China and Singapore, have attempted to emphasize their independence by substantial investment in shipbuilding and associated technologies. This has distorted the scenario even further, providing an over-production capacity of some three to one against potential orders.

Of greater concern is the current investment in associated research and development by these countries which has to be compared with the relatively small activity shown in Europe and the USA.

The fact that Western nations are no longer the sole producers of consumer goods, electronics, etc. has also shifted the operating fulcrum to the benefit of the Far East, particularly as the latter wish to exercise control over the destiny of their own products, and hence maintain their own fleets supplied by their own yards.

High-speed trafficking in high value goods such as electronic, scientific equipment, medical supplies, etc. could show some potential in the future as too could barge carrying, integrated, multi-purpose vessels, etc. As offshore sources produce 20 per cent of the world's total oil requirements, support vessels, specialized short route tankers, etc. could demonstrate some marginal growth. Any further comments regarding Ro–Ro (roll-on, roll-off), catamaran pipelaying vessels, etc. would be purely speculative and in consequence are best left to fill the percentage remaining unspecified in estimating world tonnage requirements.

A review of the OECD GNP growth rates over the past few years shows a healthy trend upwards led by the boom in the US economy. Furthermore, the drop in crude oil prices caused by reduced demand and the need to obtain finance for local war support (Iraq/Iran) or unsustainable, uneconomic indigenous growth (Nigeria, South America) should accelerate the economic recovery of other nations, particularly if the exchange rate of the dollar weakens.

That, unfortunately, is the 'good news'; the 'bad news' is that the US economy is currently exhibiting a huge budget deficit which may only be contained by high interest rates or inflation. A large increase in the latter is considered to be unacceptable and, although a compromise will be attempted, it seems logical to assume that the US-led economic growth has peaked this year and the only way forward for the OECD GNP is down.

The associated ship demand over the past few years is shown in Fig. 9.

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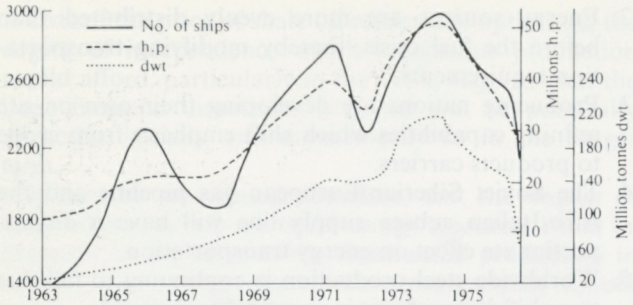


Fig. 9 Trends in total shipborne trade

2.1 Demand

As indicated earlier, world oil consumption has essentially 'plateaud' after a decline and will probably remain fairly constant for the next three to five years. Also the broader distribution of oil production developed over the past decade and the general OECD reduction in requirements suggest, in turn, that the tanker market is at best dormant and in reality in a situation of serious decline (Fig. 10).

The relative growth in gas utilization, particularly by Japan and the USA, will ensure some related growth in demand for LNG carriers—a situation which will probably exist until 1990 and possibly a little beyond.

With respect to a possible demand in bulk carriers, world steel production is in decline, particularly in OECD nations, not only due to the general recession, but also because of the increased availability of new materials. This also has a similar effect on the movement of iron ore and no change in the situation is expected in the next five years.

Coal transportation shows a tendency towards a relatively small growth, i.e. 3 per cent or so per annum for the next two or three years which is certainly not proportional to actual coal consumption as many countries are developing their own resources or those of their neighbour as opposed to buying worldwide.

The USA, due to large grain surpluses over many years, implemented a plan to reduce over-production and was immediately hit with heat waves at a critical time in the growing season. This ensured that world grain stock was reduced by up to 30 per cent. The USSR, traditionally the largest importer of grain products, has, with much effort, increased its production to a value in excess of 200 million tonnes for the first time and is investing more. Therefore, although the world population will continue to require more grain, growth in sea transportation will not be commensurate with demand and hence an increase in tonnage movement of 2–3 per cent per annum over the next few years seems an equitable expectation.

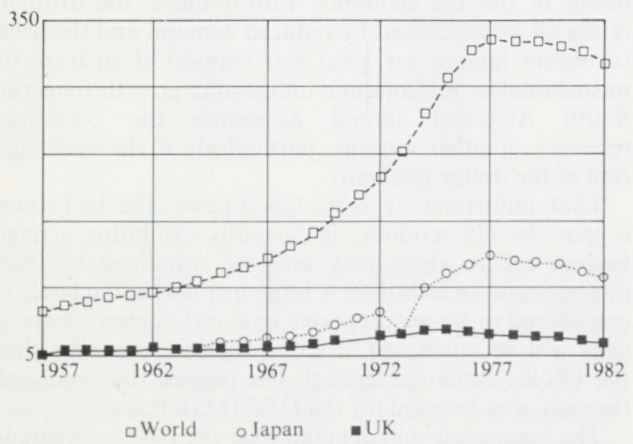


Fig. 10 Tanker fleet comparison

2.2 Summary

1. Assuming no major worldwide conflict there will be a distinct decline in the rate of growth of the industrial nations.
2. Overall growth in sea transportation may reasonably be expected to average 3 per cent.
3. The oil tanker market will show some growth but this will not be truly identifiable until approximately 1987.
4. Product tanker demand should continue to improve due primarily to the diversification of manufacture of oil derivatives and the international dispersal of refinery plant.
5. Industrialization of the developing nations will increase the demand for special products vessels.
6. Dry bulk transport requirements will continue to grow in relation to population growth and to some extent in response to some shift of emphasis to coal as an energy source (3–4 per cent).
7. Growth in specialized products will assist demand in the general cargo trading position.
8. Technological evolution will encourage the design and development of vessels for specialized applications, particularly for high-speed trafficking of high value goods and the supply of offshore developments.
10. The expansion of the USSR merchant fleet if permitted to continue unabated will absorb a substantial proportion of the demand predicted, particularly in the area of dry bulk carriers.
11. World manufacturing capability exceeds demand by at least 300 per cent.

3 POWER PLANT REQUIREMENTS TO THE YEAR 2000

3.1 Introduction

Figure 11 indicates the factors involved in the selection of the main propulsion system for any given application. Substitution of the necessary data leads to the conclusion that fuel cost is the most significant economic factor to be considered over the life cycle of a ship. As more and more emphasis is placed on the scarcity and hence value of hydrocarbon fuel sources, it is plausible to suggest that any techno-economic assessment of ship purchase and deployment in the future will lead to the conclusion that fuel economy, rather than first cost, will form the basis of any decisions made and subsequent orders placed.

Figure 12 predicts the 'power to weight' ratio for the range of vessels considered projected over the next twenty years.

The total power plant requirement in the year 2000 should approximate to 16×10^6 kW of which the majority will be diesels. Obviously, hybrid systems could be involved in any or all of the three main classifications where the heading used refers to the principal power unit.

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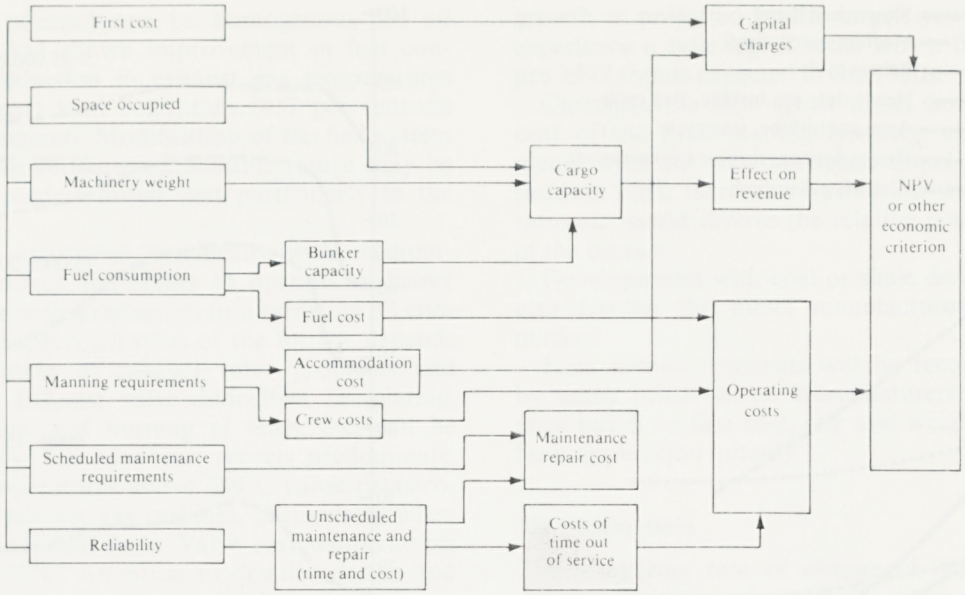


Fig. 11 Method to calculate net present value for main engine

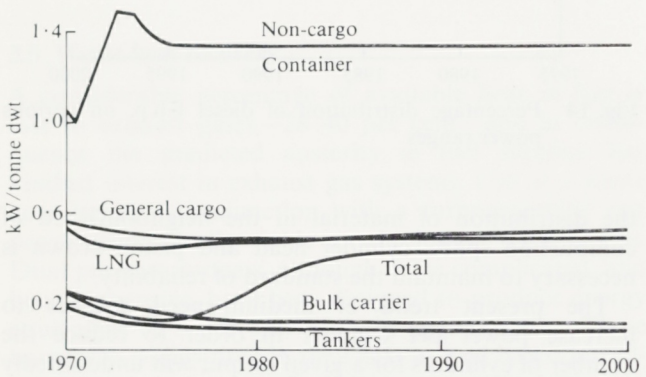


Fig. 12 Specific marine power trends

3.2 Fuel quality

Recently there has been a marked tendency towards the combustion of relatively poor quality fuels in propulsion plant at sea in a further attempt to minimize operational costs. Reliability of the prime propulsion element has been, to some extent, affected by the use of these fuels due to the incompatibility of intrinsic contaminants with engine components and lubricating fluids.

In addition to the 'usual' contaminating materials such as silicon, rust and water, these 'residual' fuels contain large quantities of asphaltines—up to 10 per cent by weight. Apart from being highly aromatic, these materials tend to block filters because of their ability to congeal with other undesirable problem particles. Removal of these aromatic materials tends to reduce the calorific value of the fuel by a perceptible margin (one part to 2000 or 4000 depending upon the degree of contamination) and therefore chemical treatment is generally preferred as a means of reducing the overall detrimental effect.

Other significant problems include fuel stratification leading to bunker incompatibility and the effect of wax contamination on filters and heating coils, etc. Additional storage requirements needed to combat the relatively high viscosity of the material also tends to the overall expression of 'unsociable fuels'.

Table 3 Corrosive and abrasive constituents in heavy fuel

		Melting point °C
Vanadium pentoxide	V_2O_5	690
Sodium metavanadate	$Na_2O \cdot V_2O_5$	630
Sodium pyrovanadate	$2Na_2O \cdot V_2O_5$	640
Sodium orthovanadate	$3Na_2O \cdot V_2O_5$	850
Sodium vanadate—IV, V	$Na_2O \cdot V_2O_4 \cdot 5V_2O_5$	625
Pentasodium vanadate—IV, V	$5Na_2O \cdot V_2O_4 \cdot 11V_2O_5$	535
Ferric metavanadate	$Fe_2O_3 \cdot V_2O_5$	860
Ferric vanadate	$Fe_2O_3 \cdot 2V_2O_5$	855
Sodium sulphate	Na_2SO_4	880

Typical unwanted but included constituents of heavy fuel oils are shown in Table 3 and a contaminant 'weight count' is shown in Table 4.

Even with the inclusion of fuel treatment plant, the use of 'heavy' fuel still presents difficulties associated with ignition delay and subsequent relatively large rates of change of pressure when used in diesel engines and demand detail development and specialized research attention. These and other aspects are referred to below.

Table 4 Composition of turbocharger blade and nozzle deposits

	% Weight
Vanadium	28
Calcium	10
(as $CaSO_4$)	(20)
Sodium	>1
Sulphur	8·2
Nickel	4·2
Iron	>1
Zinc	>1
Magnesium	Trace

3.3 Diesel propulsion—status

Figure 13 indicates why diesel drive systems have in recent years achieved a monopolistic position in the marine propulsion market, particularly in the low to medium power ranges. The current aim of the diesel

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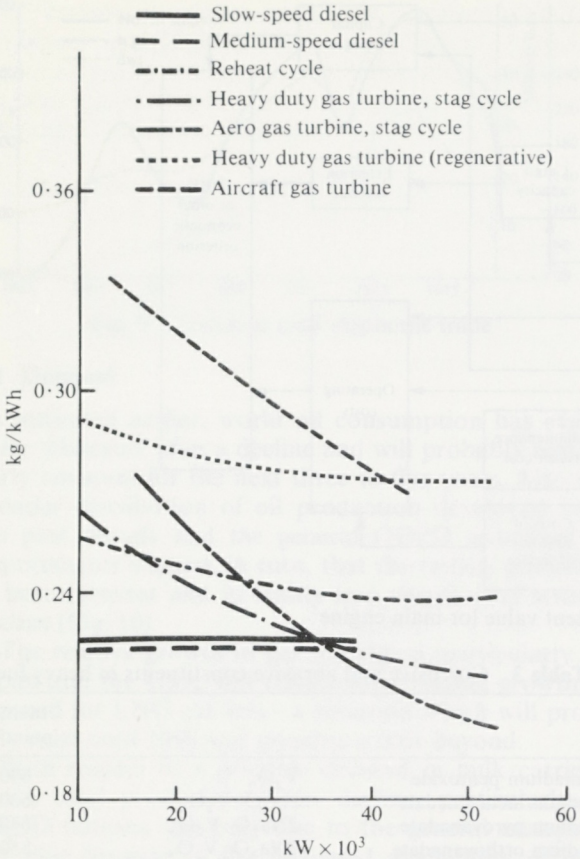


Fig. 13 Overall specific fuel consumption in shipping

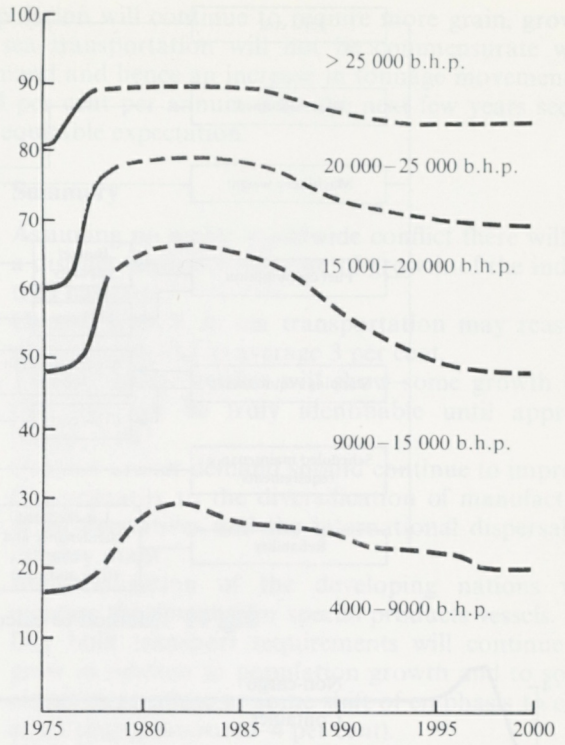


Fig. 14 Percentage distribution of diesel b.h.p. on various power ranges

engine manufacturing industry is to improve reliability, reduce fuel consumption, noise and vibration and to offer engines capable of efficient operation using an ever widening spectrum of fuels.

3.4 Reliability

The need to use low grade fuels while maintaining or increasing the present level of b.m.e.p. aggravates some of the problems of the diesel engine, particularly if reduced power slow-speed running has to be maintained for extended periods.

The wear rates of piston rings (particularly the top one) and liners are adversely affected (increases of 100 per cent have been reported), and require further development of special lubricating oils and new material combinations.

The use of fuels with low cetane value increases the shock loading within the engine, with particularly adverse influence on the top piston ring. At slow-speed conditions, the atomization is relatively poor, maximum combustion temperature is lower and there is increased tendency to precipitate carbon residues leading to a marked reduction in reliability. There is thus a need to develop a constant pressure injection system which, together with modifications to combustion chamber design, should serve to improve reliability. The incorporation of scavenge air heaters (to heat air to 80°C) will also help improve combustion conditions for slow-speed running below 45 per cent maximum continuous rating.

For full power operation, as b.m.e.p. is increased, so too are thermal stresses and continued development in the distribution of material in the neighbourhood of combustion space, cylinder head and piston crown is necessary to maintain the standard of reliability.

The present trend of medium-speed engines to increase power per cylinder in order to reduce the number of cylinders for a given output will undoubtedly continue, using increased density of air charge which in turn requires further developments of exhaust gas turbines and compressors. As developed these engines will continue to expand into the domain of both slow-speed diesels and steam plant due to the flexibility and reliability of operation afforded by multi-engine installations. Figure 14 gives an indication of current and anticipated diesel power distribution.

3.5 Fuel consumption

Factors directly affecting improvements in specific fuel consumption are:

(a) development of high-pressure injection systems together with improved mixing processes;
(b) improvements of turbocharger efficiency.

Present development work on high-pressure injection systems indicates that savings of 5–6 g/kWh can be expected at normal full load with even greater proportional savings at part load. Careful attention will have to be paid to nozzle design and manufacture, and to operational temperature control.

The constant pressure system of turbocharging is the most efficient for pressure ratios in excess of 2.2 to 1; it is widely used at present and will continue to be used. For pressure ratios in excess of 3.5 to 1, new materials may have to be used to permit higher speeds of rotation.

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The injection of emulsions, i.e. homogenous fuel oil water mixtures, has shown improvement in fuel consumption and reduction in exhaust gas temperatures particularly at part load conditions (4–7 per cent on medium-speed engines). Modification of the fuel system is minimal and in consequence sensible return may be obtained for a modest initial cost particularly in the retrofit market.

Requirements associated specifically with medium-speed engines include the ability to operate on heavy fuel oils together with a reduction in lubricating oil consumption. Successful realization of the former depends upon the resolution of exhaust valve problems and turbine fouling. Exhaust valve difficulties, i.e. plating, corrosion, erosion and burning of seats, etc. can be solved technically, but economic aspects predominate. Exhaust gas temperatures above 550°C cause catastrophic fouling of exhaust gas turbines, particularly when using heavy or residual fuels. Valve seat temperatures are limited to 450°C. Attention to detailed design and selection of materials should permit lubricating oil consumption levels below 1 g/kWh to be realized.

3.6 Waste heat recovery

A considerable percentage of available heat in fuel is lost to exhaust gases—28–40 per cent—and in consequence the predicted austerity in fuel supplies has kindled interest in exhaust gas systems. Use of a waste heat boiler in conjunction with a turbogenerator can prove economically viable on the longer trade routes. Dual pressure systems, although more complicated, and hence expensive, have been designed to produce energy equivalent to 9 per cent of main engine power. These have been widely used in the USA on land based installations and on sixteen BP tankers using 5600 kW main engines.

Recent trends have been towards the design and construction of fully integrated plant using waste heat recovery systems and main engine derived electrical power generation. Such systems provide an effective energy utilization in excess of 70 per cent making them the most efficient diesel power generation systems available anywhere.

3.7 Diesel engine demand

Table 5 attempts to project the industry's requirements over the next twenty to twenty-five years.

A cursory glance suggests that, after some initial growth in the low power range, demand should stabilize through the period under consideration. Although growth is projected in the larger power range, it will experience a time lag of some ten to fifteen years with pre-1977 trends expected in the 1990s.

Currently the slow-speed diesel holds some 65 per cent of the total market, however, expected developments with the medium-speed diesel with respect to residual fuels, increase of power to weight to cylinder ratio etc. could reverse the relative position at the turn of the century.

Developments with coal or shale derived fuels should also harden the diesel manufacturers' hold on the market.

Heat recovery systems will be recommended extras by many prime mover manufacturers but sales resistance based on first cost, size and weight could severely limit application initially.

3.8 Steam plant

The staggering rate of change of fuel price has had disastrous repercussions on the steam propulsion plant industry. In 1978 only thirty-two ships were completed worldwide and in 1984 only eight utilizing steam plant. Attempts are being made to maintain some vestige of a 'steam' industry in Japan and the USA, the latter primarily because of its naval involvement in nuclear propulsion and the former because of its shift to a reliance on coal.

Figure 15 gives the relative operational cost of the various propulsion plant options and underlines the problems which face the steam plant specialist. The difficulties are further emphasized by the industry's reliance on slower, smaller, more economic ships. Even at large power levels, however, ships are being designed and built with diesel power. It is interesting to note that the slow-speed diesel engine is no longer supreme at horsepowers over 30000 as 280000 dwt tankers have been converted to its medium-speed competitor!

Subsequent trials have claimed advantages beyond that of fuel economy, i.e. a reduction in stopping distance and time and economic/maintenance operation due to the availability of a multiplicity of plant.

Although the steam plant manufacturers are attempting to fight back with more sophisticated technology to reduce fuel consumption, first cost and complexity tend to prevent any serious interest from the beleaguered ship owner. An attempt has been made to provide simpler designs capable of meeting the optimum 10000 h.p. requirement using fluidized bed combustion technology, but the potential market is still very small and consists primarily of specialist applications, *viz.* coal carriers, etc.

Table 5 Projected distribution of diesel b.h.p. on various power ranges

	$4–9 \times 10^3$ b.h.p.		$9–15 \times 10^3$ b.h.p.		$15–20 \times 10^3$ b.h.p.		$20–25 \times 10^3$ b.h.p.		$>25 \times 10^3$ b.h.p.		
	3–6·75 MW		6·75–11·25 MW		11·25–15 MW		15–18·75 MW		>18·75 MW		Total
Year	%	kW × 10^6	%	kW × 10^6	%	kW × 10^6	%	kW × 10^6	%	kW × 10^6	kW × 10^6
1980	27	2	38	2·85	12	0·91	11	0·83	12	0·91	7·5
1985	25	2	40	3·3	12	0·99	11	0·92	12	0·99	8·2
1990	23	2·1	34	3·05	16	1·45	14	1·25	13	1·15	9·0
1995	22	2·2	30	3·0	20	2·0	14	1·4	14	1·4	10
2000	20	2·25	28	3·15	22	2·5	15	1·65	15	1·65	11·2

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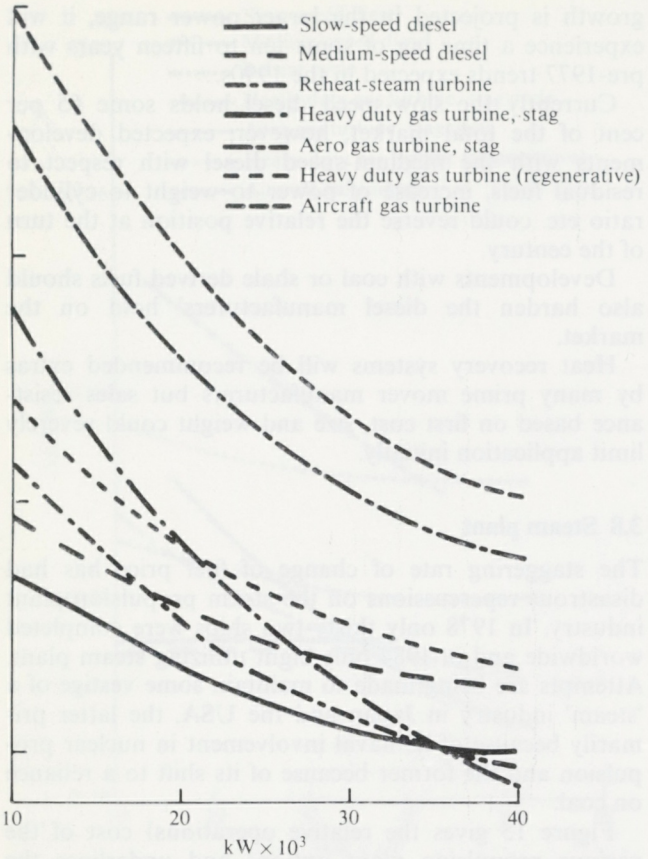


Fig. 15 Annual operating costs of various marine power plants

3.9 Gas turbines

Claims for gas turbines are itemized in Table 6, and underline the reason for their popularity in military and fast long haul trading vessels.

Regenerative cycles with reheat and intercooling offer considerable advantages over simpler systems in terms of power and efficiency but exhibit penalties including weight, size, complexity, etc.

Use of the gas turbine as a prime mover is limited by the following:

(a) unproven capability to burn 'bunker C' in an efficient and reliable manner;
(b) reversing difficulties;
(c) poor part load performance.

Progress in recent years in material development and transpiration cooling techniques, etc. have made it possible to increase maximum operating temperatures by approximately 10°C per year with an appropriate improvement in fuel consumption. Controllable pitch propellers are increasing in use and size, therefore, the reversing problem is eroding with time.

Part load performance can be improved by using variable geometry turbine guide vanes, etc. and further gains in this area may be expected although at a price.

Reflection on the above suggests that gas turbines could present a viable alternative to more traditional power plants but probably in combined cycle operation and only in specialized applications, *viz.* LNG carriers and general military use.

Table 6 Gas turbine characteristics

1. Low specific weight (kg/kW)
2. Low specific volume (m^3/kW)
3. Low specific first cost
4. Minimum requirements for external auxiliary systems
5. Environmental acceptability (emissions, thermal pollution etc)
6. Vibration free
7. Very low lubricating oil consumption
8. Low installation cost since no heavy foundations are necessary
9. Flexibility of installation due to low weight, small size, and no vibrations
10. Ease of maintenance, and low manning requirements
11. Ease of automation

Against the above stated advantages of the gas turbine consider the following main disadvantages:

1. Higher fuel consumption
2. Sensitivity to fuel contamination
3. Poor part load performance

3.10 Summary

1. Although there has been a marked tendency towards the combustion of relatively poor fuels, this tendency is expected to stabilize shortly.
2. Alternative fuels will become available in approximately five to ten years' time; however, it is anticipated that assuming no major catastrophes, sufficient fuel of acceptable quality will be available to the marine field for the foreseeable future.
3. The diesel engine will consolidate its position as the world leading prime mover. There will be a perceptible shift of emphasis from the slow-speed to the medium-speed diesel propulsion power plant with the latter being in the majority.
4. Considerable research will be applied to problems associated with reliability including the combustion of relatively low quality and non-aesthetic fuels.
5. The constant pressure turbocharger will predominate, pressure ratios will increase. Overall fuel consumption will decrease as a result of the higher specific power to weight ratio.
6. Overall electronic control will be commonplace at the turn of the century.
7. Waste heat recovery systems will be fully integrated.
8. Steam plant will remain in decline, the majority of systems being manufactured in the USA for its own shipping although specialized applications will occur particularly for Far East trade.
9. Although more sophisticated alternatives of steam plant will be offered, their inherent complexity will maintain the trend toward diesel utilization.
10. Continued development of application of the fluidized bed reheat systems should assist in the maintenance of some steam plant at sea.
11. With the exception of specialized applications, i.e. military warships, LNG carriers, etc. the gas turbine will play a subservient role to other forms of plant. Some considerable application will occur in waste heat recovery gas turbine systems, i.e. as auxiliary power generation.

4 CURRENT RESEARCH

The future of the UK as a viable independent maritime nation depends on its ability to compete in the world market both in quality and, to some degree, price. However, its prime opportunity lies in innovative tech-

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nology, where it must obtain and maintain a fundamental lead.

Even though the need is urgent—witness the savage continuing decline in the shipbuilding and marine industries—the risk of failure would be a total disaster and a rational well-reasoned approach is essential; hence this proposal.

In spite of the apparent re-emergence of sail, power generation using relatively conventional combustion techniques will always be required both for offshore applications, i.e. platform services, sub-surface power and life support, and also for main propulsion at sea.

With respect to the latter, four fundamental opportunities exist for an improvement in operational efficiency:

1. Reduced fuel consumption.
2. Crew minimization.
3. Increase in reliability.
4. Increased availability and safety.

The development of the diesel engine is rapidly reaching viable limits with respect to overall brake thermal efficiency, the cost/per cent of fuel utilization reaching mammoth proportions—£3.5 million per 0.5 per cent improvement in fuel economy being reported. This, in a depressed and competititve market, is difficult to recoup in terms of sales.

Crew minimization and system reliability are interlinked. The first cannot be achieved without a significant improvement in the latter. The achievement of improved reliability appears to be incompatible with the combined pressure of demand for improvement in fuel consumption, together with a continuing deterioration in fuel quality. The objectives are further complicated by the movement towards the integration of the auxiliary power system with the main engine and possible introduction of new fuels—tar sand and shale oil derivatives, for example.

It is, therefore, thought to be mandatory to implement a core project definition study with the intention of applying techno-economic and redundancy techniques to the analysis of a fully integrated power systems concept.

The majority of pure research projects being undertaken on behalf of the marine industry are within the university system. Several centres have been set up throughout the UK with Science and Engineering Research Council (SERC) support, each emphasizing a particular aspect of marine technology. At the risk of being partisan, Newcastle is perhaps unique because of its ability within the School of Marine Technology to draw upon the resources of the Departments of Marine Engineering and Naval Architecture and also the Ocean Engineering Group. Furthermore, the resources of the School are augmented by drawing upon related skills within the Faculties of Engineering, Medicine, Science and School of Agriculture.

Space prevents all the projects presently under development from being assessed here; however, a list is provided in the Appendix and in addition a few specific examples are amplified below.

4.1 Subsea power generation

Some years ago it was suggested that there would be a need in the future to develop power on the sea bed (**1**). Obvious applications include pumping power for oil distribution networks, auxiliary or emergency power for sub-surface habitats and also submersible propulsion/life support.

The advantage of providing the capacity to produce pumping power on the sea bed as opposed to delivery from the surface is manifest in effective energy utilization; the power source acts at local ambient conditions and uses generated heat for the required purpose rather than to overcome adverse pressure differentials.

Further, the capacity of a submersible to operate without an umbilical cord and at power levels in excess of the current generation of machine would enhance efficiency and safety. The opportunity to install a back-up environmental support power system in a 'diver's haven' or sub-surface habitat, should power from the surface be disrupted, would also prove to be 'not unwelcome'. In response to this demand a feasibility study (**2**) was instigated to determine the most effective means of satisfying the potential demand. Flexibility of operation and application together with the utmost reliability were the prime goals.

Many systems were evaluated from power cells through batteries and Stirling engines to micro-nuclear plant, but in the final analysis the diesel engine satisfied more of the stipulated requirements than any other potential source (Tables 7 and 8). Data retrieved from Thompson (**1**) indicate the assessed advantages. If chemical methods of power generation are ignored then the reason for selection of the diesel engine may be as summarized in Table 9.

Because of the range of application it was decided to press ahead with a depth independent design, i.e. the recycle engine (**3**, **4**). Essentially, the exhaust gases are cooled, scrubbed of carbon dioxide, enriched with oxygen from a liquid oxygen source, and reintroduced to the combustion chamber. Although simple in theory and relatively easy to demonstrate in a very short-term steady state manual control mode, substantial research was required to prove the concept on a commercial basis.

Table 7 Comparison of energy storage systems

Storage system	Specific gravity	Nominal temperature °C	Energy capacity kWh/kg	Energy density kWh/l
Lithium hydroxide	1.41	473	0.71	1.0
Lithium fluoride	2.64	848	0.29	0.77
Aluminium oxide	3.98	550	0.28	1.15
Beryllium oxide	3·01	550	0.45	1.35
Flywheel	—	20	0.02	—
Diesel oil/liquid oxygen	1.08	20	2.65	2.86
Lead acid battery	2.3	20	0.02	0.05

Table 8 Comparison of underwater power systems

Power system	Energy to weight ratio kWh/kg	Energy to volume ratio kWh/m^3	Running costs £/kWh	Capital cost £/W
Stirling engine	0.11	90	1	3
IPN turbine	0.20	160	15	3.7
Fuel cell	0.1	80	3	30.0
Lead–acid battery	0.025	50	0.2	11.0
Silver–zinc battery	0.09	150	0.2	48.0
Nitro diesel	0.11	100	1	2.7

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Table 9 A comparison of selected dynamic converters (0–100 kW)

Converter	Development cost factor[1]	Running cost factor[2]	Development availability factor	Reliability	Underwater technical suitability	Figure of merit[3]
IPN turbine	1.5	0.75	1.25	1.25	0.75	1.3
Ricardo recycle diesel	1.5	1.25	1.25	1.0	1.25	2.3
Psychrodiesel	1.25	1.0	1.25	1.0	1.5	2.3
Depth independent recycle diesel	1.25	1.0	1.25	1.25	1.5	2.9
Stirling (rhombic)	0.75	1.25	0.75	1.0	1.25	0.9
Closed Brayton cycle	0.5	0.75	0.75	0.75	1.0	0.2
Rankine cycles	0.5	0.75	0.75	1.0	0.75	0.2

Notes
1 Development cost factor proportional to reciprocal of development cost
2 Running cost factor includes an allowance for fuel consumption and maintenance
3 Figure of merit is product of individual factors

Fowler (**5**) detailed the concept and approach in his paper to the Institute of Marine Engineers in 1984 which is essentially as follows:

1. Develop extensive instrumentation capability.
2. Analyse exhaust constituents at transient loads.
3. Define and develop composite mathematical models.
4. Determine dynamic and steady state operating parameters.
5. Design and construct a totally flexible experimental facility.
6. Design and implement a comprehensive control system.

Figure 16 shows a schematic of the system and Figs. 17 and 18 the simulated and measured transient response.

It should be noted that the hybrid computer simulation was sufficiently exact to permit an effective control system configuration to be implemented which not only maintained a sensible 'air/fuel' ratio at all operating conditions, but will also permit cold automatic start-up either naturally aspirated or closed cycle.

Currently, emphasis is being placed on a more effective space/material consumption scrubbing system with preliminary results proving most encouraging. A further useful aspect of the design is the potential for increasing its effective power/density ratio by utilization of exhaust gas heat transfer.

Success ensures that application will be almost limitless.

4.2 Combustion technology

4.2.1 Emulsified fuels

Staff of the Department of Marine Engineering at the University of Newcastle upon Tyne have pioneered the application of emulsified fuels in diesel engines, gas turbines and boiler plant (**6**, **7**, **8**). The process involves mixing, by specially developed mechanical means, water with fuel oil prior to injection into the combustion.

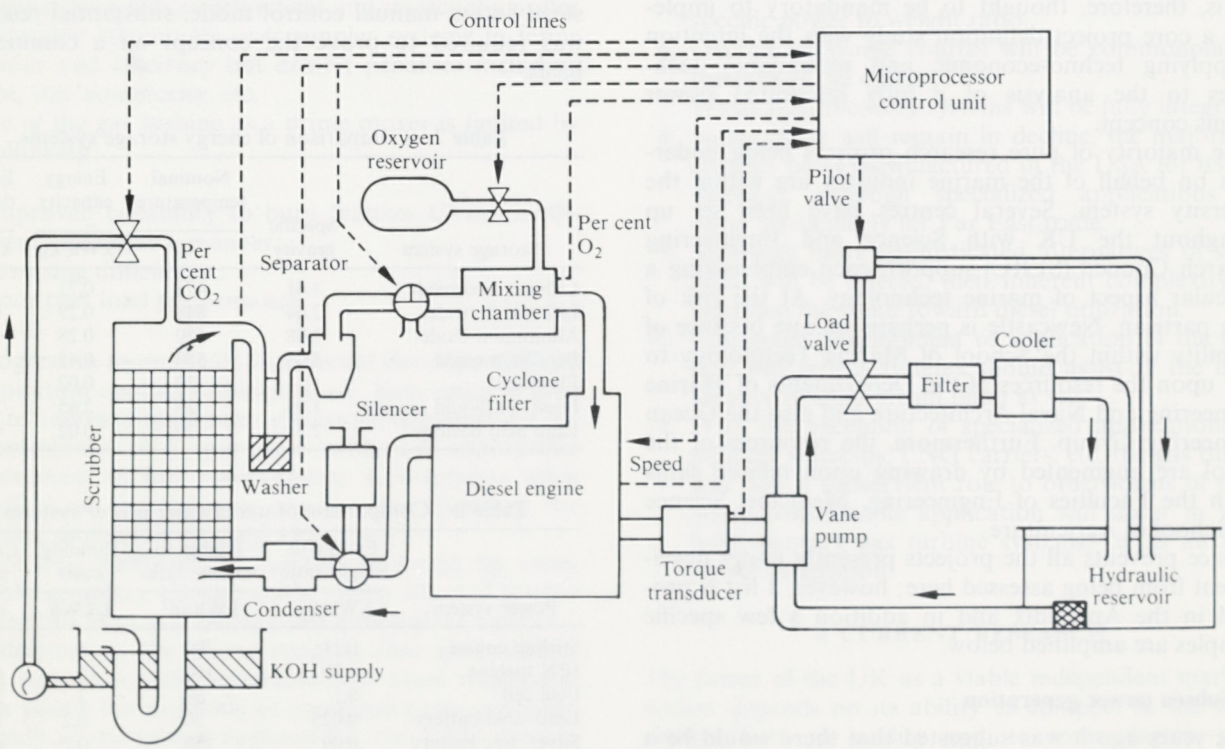


Fig. 16 Schematic of closed cycle diesel system

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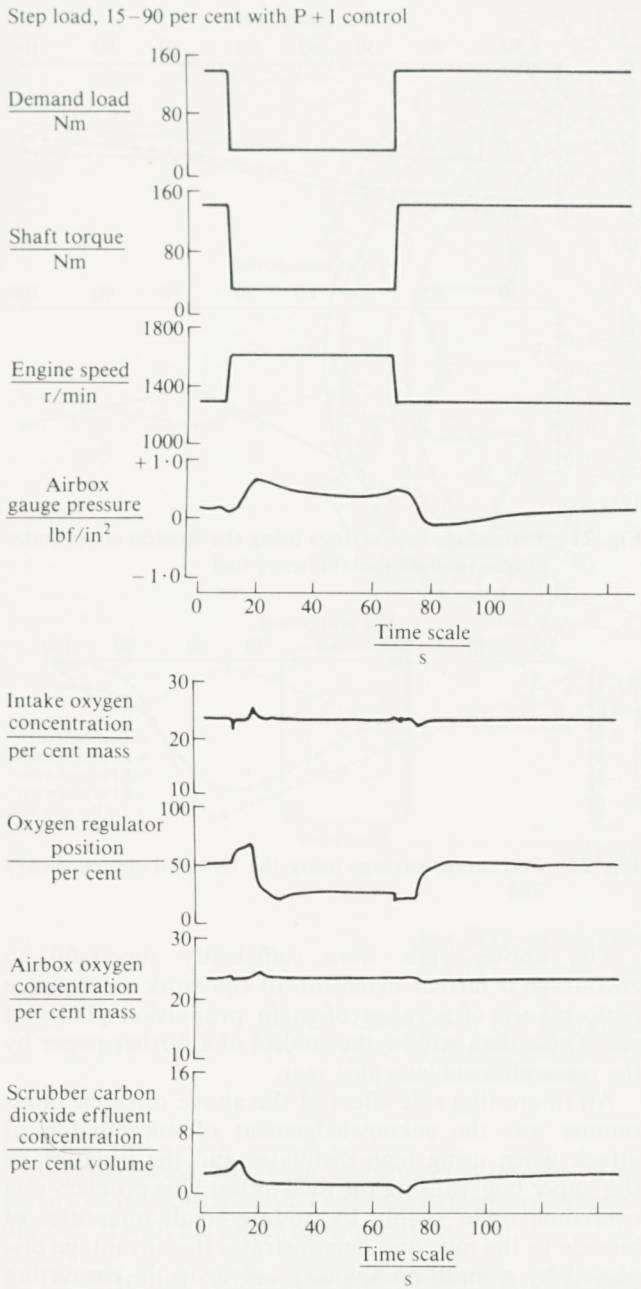


Fig. 17 Step response of validated simulation model

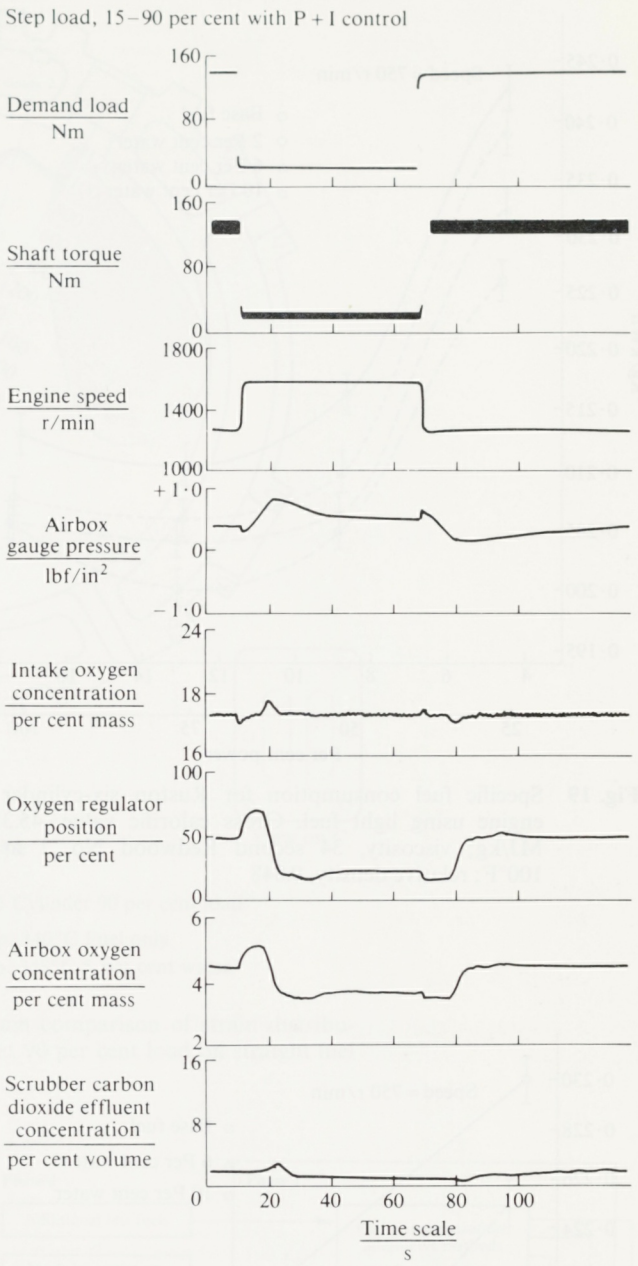


Fig. 18 Step response of test rig

A major project funded by the Department of Industry had the following prime objectives:

1. Evaluation of proprietary emulsification/homogenization systems and devices in terms of product properties and suitability of application.
2. Development of a medium-speed engine facility within the Department of Marine Engineering, suitably instrumented to meet the stringent experimental requirements.
3. Construction of a fuel recirculation rig capable of investigating, on a long-term endurance basis, the effect of various ratios of water/oil emulsions on fuel system components.
4. Evaluation of the performance of a standard slow-speed diesel engine when subjected to a range of water/oil emulsions.

Figures 19, 20 and 21 display typical results measured on the six-cylinder Ruston medium-speed research engine. It may be seen that significant fuel economy is evident over the power range of this particular engine when operating on both diesel and heavy fuel oil, usually accompanied by a parallel reduction in the production of NO_x.

Of significant interest was the fact that water impregnated fuels permitted combustion of 900 Redwood second oil in an engine which was not designed for this material.

Figure 22 shows typical results on the Doxford 58JS three-cylinder slow-speed engine when burning 'bunker C' fuel oil. Sadly this fine British engine enjoyed a very short life due to the closure of the manufacturing plant for economic reasons. Figure 23 shows an interesting phenomenon measured on a sister engine, the Doxford 67J6, when burning emulsified fuels, i.e. a measurable reduction in thermal stress in the cylinder liner when producing equivalent power.

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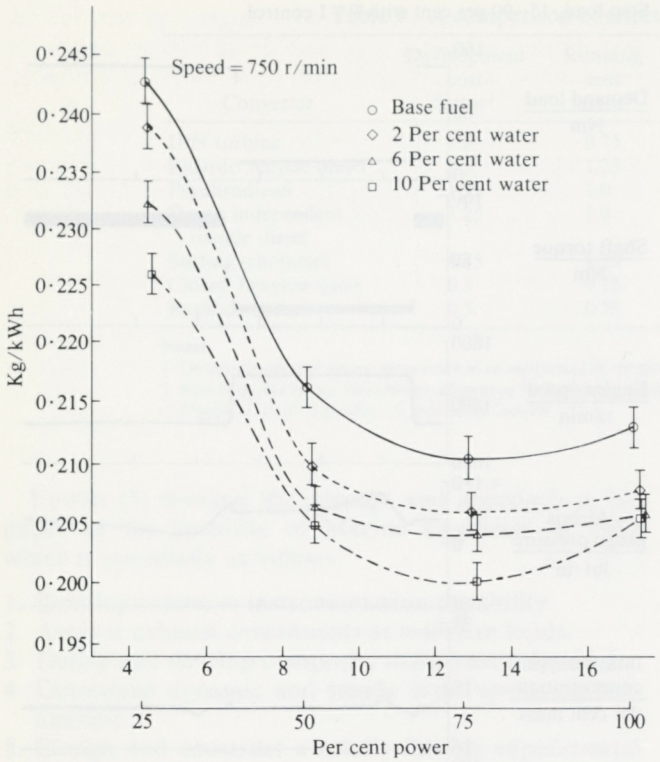


Fig. 19 Specific fuel consumption for Ruston six-cylinder engine using light fuel. Gross calorific value, 45.3 MJ/kg; viscosity, 34 second Redwood No. 1 at 100°F; relative density, 0.848

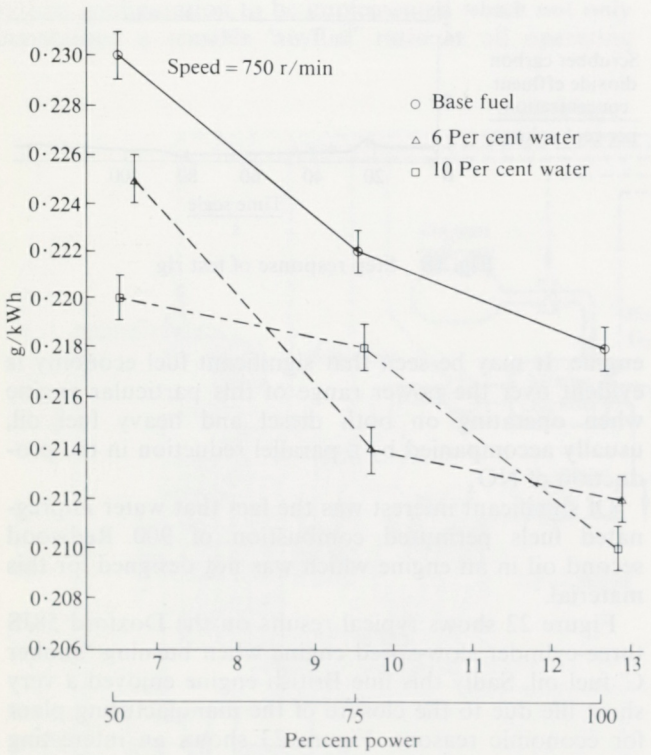


Fig. 20 Specific fuel consumption for Ruston six-cylinder engine using heavy fuel. Gross calorific value, 44.3 MJ/kg; viscosity, 990 second Redwood No. 1 at 100°F; relative density, 0.93

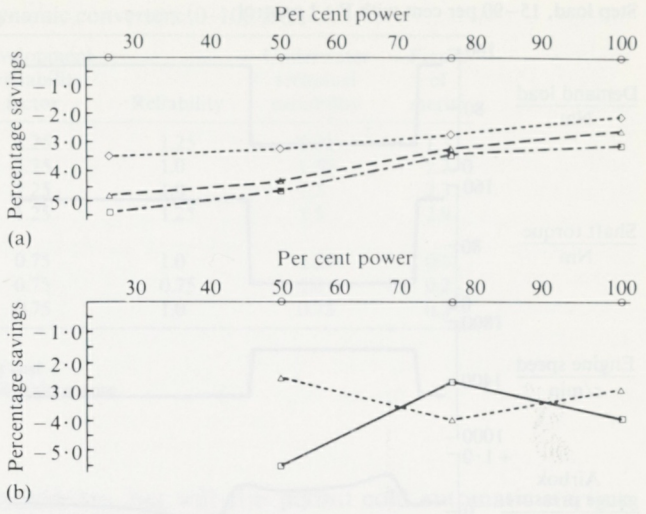


Fig. 21 Percentage fuel savings using the Ruston six-cylinder engine (a) light fuel (b) heavy fuel

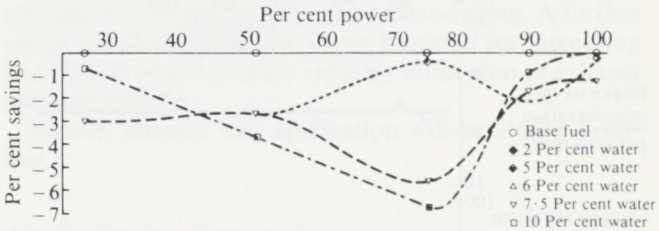


Fig. 22 Percentage savings using the Doxford engine: heavy fuel

The above trials were sufficiently successful to encourage a further extension of the work to measure performance of a range of main propulsion plants at sea. These data will be the subject of a further paper by the research team later this year.

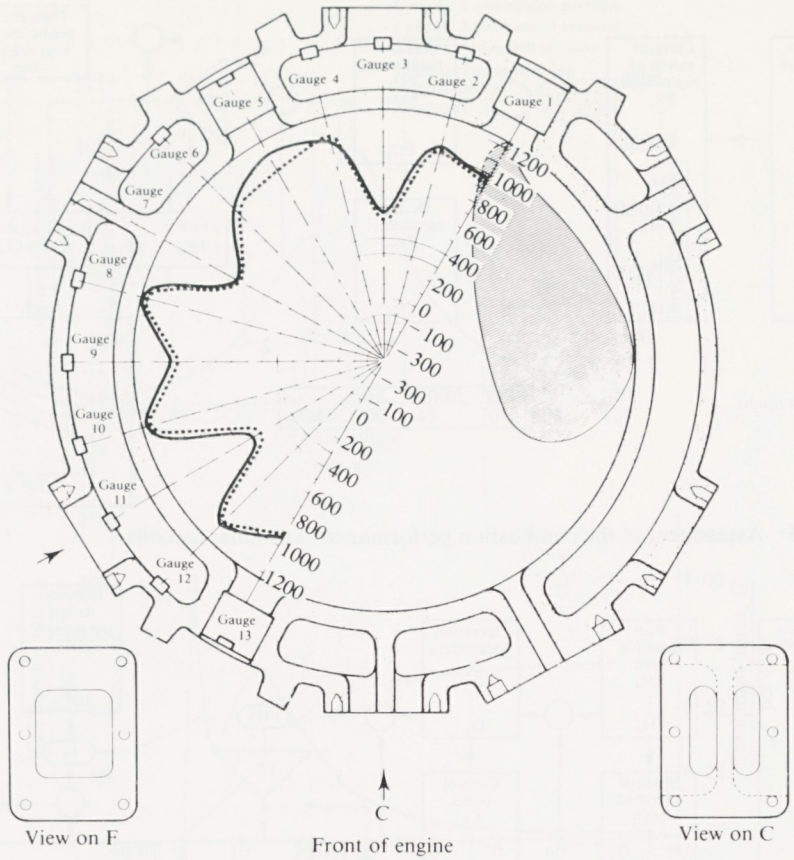
An interesting side effect of the above research programme was the acknowledgement of microbiological attack when using high distillates and the isolation of the 'super bug' causing the difficulties. This problem was overcome quite simply by adding small quantities of biocide to the mix, and demonstrates the advantage displayed by a multi-disciplinary university in permitting engineers and microbiologists to work in concert to overcome a problem.

4.2.2 Fuel characterization

From earlier sections of this paper it is apparently clear that although fuel should not be in short supply its quality and constituent content cannot be guaranteed. It is not inconceivable that in the foreseeable future a ship may be supplied with fuel derived from conventional crude in Europe; in the USA a tar/shale oil derivative and oil from coal (Sasol) in Africa or Australasia. Consequently the power plant and fuel handling system will have to display a degree of tolerance to combustion not currently available, and with an expected reliability of 110 per cent!

Before the necessary engine parameters to satisfy these goals may be defined, a prediction of the effects of fuels expected to be available in the future needs to be made and the 'character' of their combustion and handling capacity evaluated.

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No. 1 Cylinder 90 per cent load

18.1.78 15–45 hours Exh. temp. 340°C Fuel only
19.1.78 17–17 hours Exh. temp. 348°C 5 per cent water

Fig. 23 Combustion belt temperature strain comparison of strain distribution for Doxford engine running at 90 per cent load on straight fuel oil and emulsified fuel

A programme has been implemented at the University of Newcastle upon Tyne (see Armstrong, Appendix No. 5) with the following objectives:

1. To determine combustion and related characteristics of a range of specially produced residual fuel oils with specific emphasis on engine reliability and operational safety.
2. To establish fuel characterization, and the corresponding test parameters, by correlating the results obtainable from various methods of fuel analysis with selected parameters on engine derived data.

To satisfy the above requirements a series of subsidiary goals were defined covering the matrix of fuels to be analysed, development of adequately fast and reliable data retrieval systems and the provision of a suitable medium-size engine with the capacity to burn reference and test fuels simultaneously. Figures 24, 25 and 26 describe the process.

Apart from the fuel handling requirements, the greatest difficulty facing the research team was that of data retrieval. It was determined that in order to obtain a viable pressure/displacement combustion characteristic, readings should be taken at each degree of crankshaft rotation which at an engine speed of 750 r/min resulted

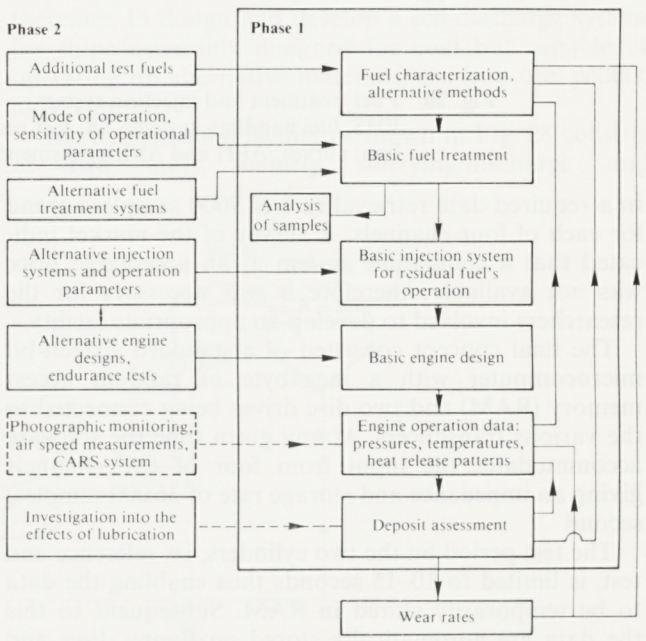


Fig. 24 Investigation of the effects of burning residual fuels in diesel engines (basic is simulation of minimum requirements for residual oil operation)

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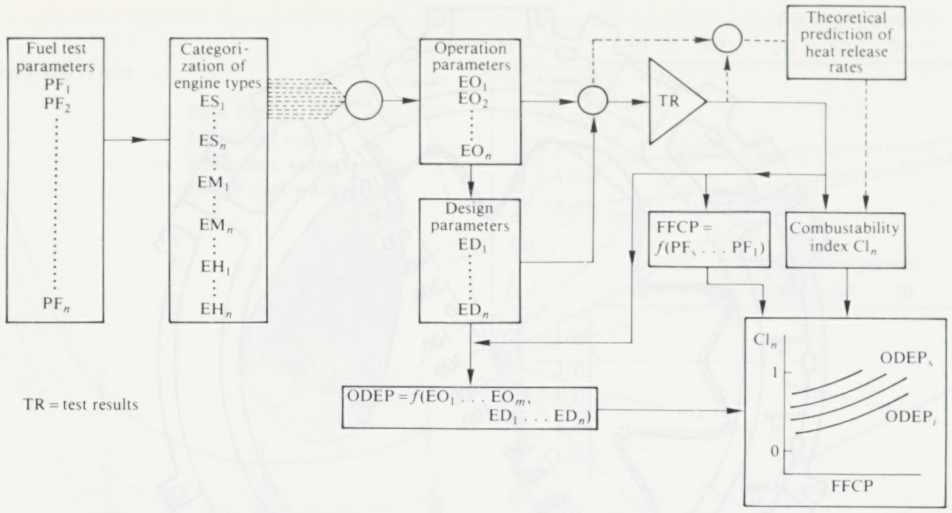


Fig. 25 Assessment of the combustion performance of residual fuel oils

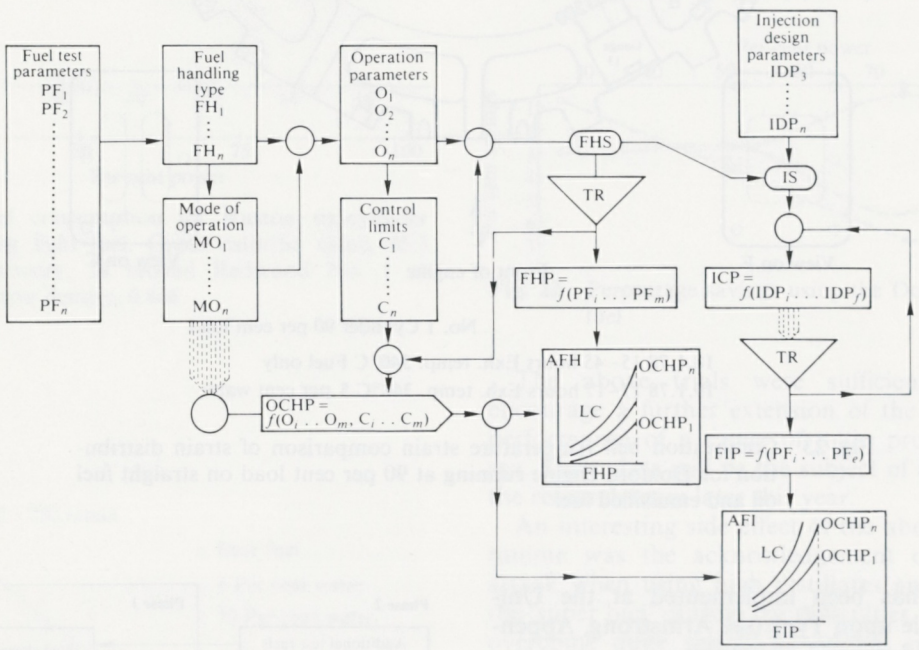


Fig. 26 Fuel treatment and injection system.
FHS, fuel handling system; TR, test results; IS, injection system; LC limit curves; AFH and AFI, assessment factors

in a required data retrieval rate of 9000 samples/second for each of four channels. A survey of the market indicated that a compatible system at an acceptable price was not available; therefore it was necessary for the researchers involved to develop an appropriate facility.

The final concept consisted of a standard sixteen-bit microcomputer with a megabyte of random access memory (RAM) and two disc drives being connected to the various transducers. At any given time the software accommodates the input from four of five channels giving an impedance and storage rate of 36 000 samples/second.

The test period on the two cylinders, i.e. reference and test, is limited to 10–15 seconds thus enabling the data to be temporarily stored in RAM. Subsequent to this the data are automatically stored on floppy discs and are therefore available for further numerical calculation/manipulation, etc. When the necessary calculations are complete the data are dumped to an X-Y plotter. Figure 27 shows the typical outputs.

The system has operated most satisfactorily permitting permanent records of the two cylinder pressures of interest, fuel line pressure at two points and needle lift to be obtained. Subsequent 'number crunching' has also proved reliable and the system is being extended to cover many other aspects of experimental data retrieval.

In addition, the engine is extensively fitted with thermocouples including in cylinder walls, pistons and exhaust valves. Cylinder wear is also monitored on a continuous basis using 'nuclear' decay methods.

Currently, the programme appears to be achieving all the stipulated requirements and it is to be hoped that the Consortium involved will permit the researchers to publish when applicable.

Ultimately it is hoped that a detailed fuel assessment procedure will permit the degree of flexibility demanded by ship owners from their propulsion plant, using adaptive control techniques.

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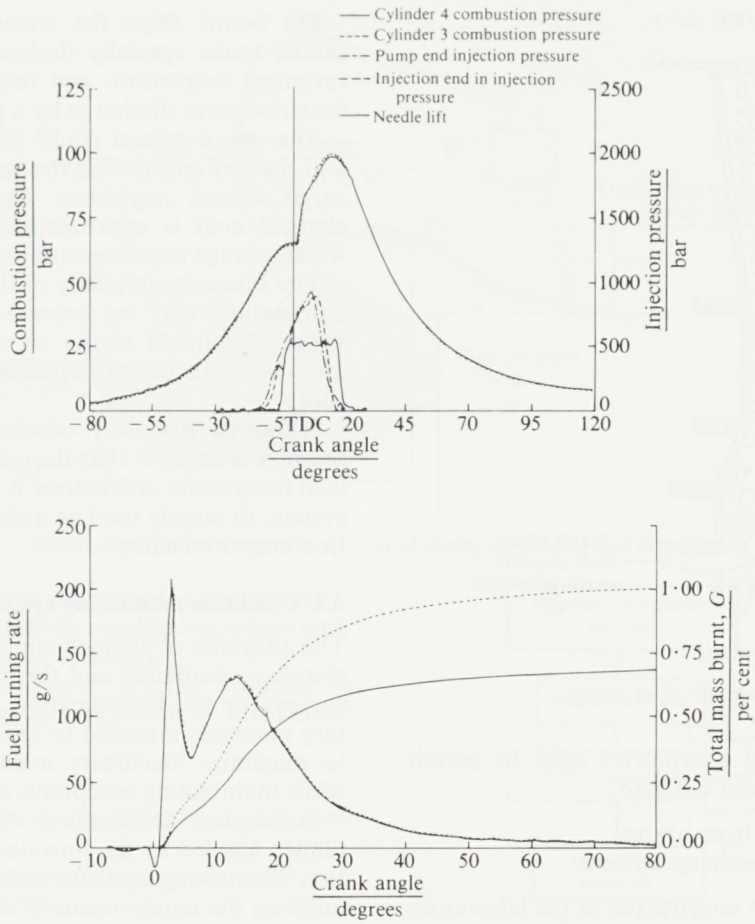


Fig. 27 Characteristics of marine fuels

4.3 Materials handling

As indicated earlier in this paper it would appear inconceivable that ship owners will revert to the burning of coal except in special circumstances, i.e. coal carriers, etc., having become accustomed to the convenience of liquid fuels. However, land based systems are not faced with similar constraints of space and in consequence it is to be expected that coal will become an increasingly important commodity in power generation.

European coal tends to be deep mined and therefore relatively expensive on the 'world scale', suggesting that the trend towards using Asian and Australasian supplies will at least continue or at best accelerate. The expected growth of so-called under-developed nations will ensure a wider distribution requirement suggesting, in turn, a need for cargo discharge flexibility. It was decided, therefore, to design and develop a self-discharge system for ships ostensibly designed for coal but capable of operating on alternative materials, *viz.* iron ore, pellets, aggregate, etc.

The experimental facility as shown in Fig. 28 consists of two units, namely slurrying/discharge and

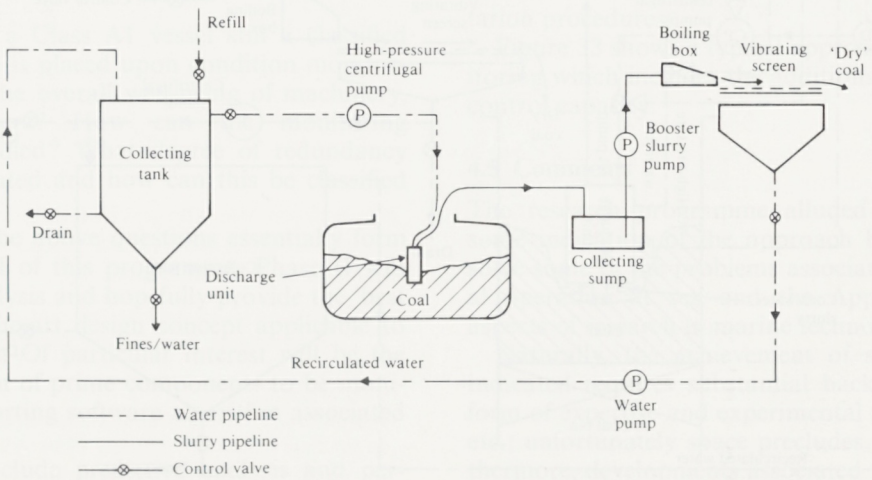


Fig. 28 Schematic sketch of the proposed coal discharge system

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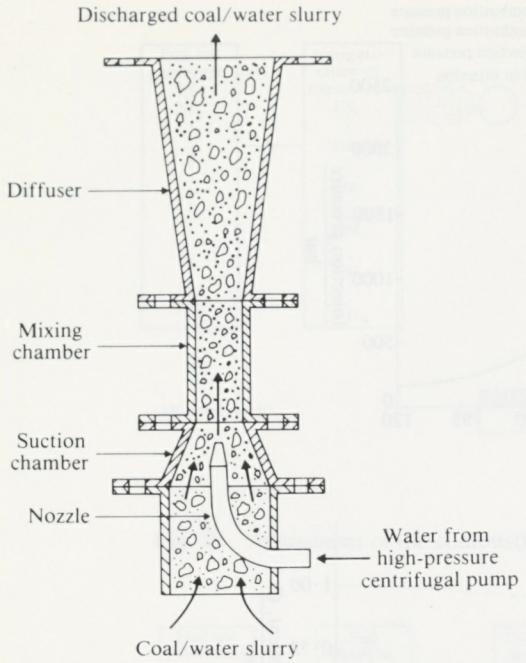


Fig. 29 Schematic of jet pump

dewatering. Two rational alternatives exist to permit removal of the material from the hold:

(a) slurry ejector lowered from above;
(b) ducted keel vacuum discharge system.

Both systems have been constructed in the laboratory (**10**) with current emphasis being placed on the former because of the flexibility which is inherent in its possible application. Figure 29 shows the jet head where it may be seen that a series of auxiliary jets slurrify the coal locally and create sufficient potential drop via the eductor tube to lift the entrained coal. The coal and water are discharged over a dewatering screen specially designed within the department to maintain resonant operation and maximum water separation. The experimental facility is shown schematically in Fig. 30.

On board ships the water would be returned to saddle tanks specially designed to maintain 'fines' in turbulent suspension and recirculated via the eductor for subsequent discharge by a process of integration.

The entire system could be self-contained on board and thereby ensure that the vessel may self-discharge its cargo almost anywhere. The dampness of the discharged coal is approximately 6–8 per cent and the water storage requirement quite modest.

The inherent simplicity of the system is such that full automation may be expected and application quite varied. Figure 31 shows an alternative mode of operation with the power requirements being held firmly on shore.

Although primarily developed for shipboard operation, it is thought that the concept could be used to lift coal from a silo and deliver it to the burners of a power system, or simply used as a pit head to storage distribution network facility.

4.4 Condition monitoring systems

The adoption of planned maintenance schemes by many shipping companies and the introduction of continuous surveys by the Classification Societies are complementary measures intended to fulfil a common objective, i.e. to maximize machinery availability at minimum cost while maintaining acceptable standards of safety.

Subsequent development of plant maintenance techniques has led to the introduction of automatic condition monitoring systems which, although theoretically fulfilling the requirements of ship owners with regard to availability and cost, do not necessarily satisfy the safety aspects demanded by the Classification Societies. Under a condition monitoring system, the inspection and maintenance of machinery is avoided until its necessity is indicated by the monitoring equipment, and there may therefore be conflict of recommendation if the inspection is not indicated within the survey period laid down by the Classification Societies.

At present, under the Classification regulations, the survey requirements take precedence, although future

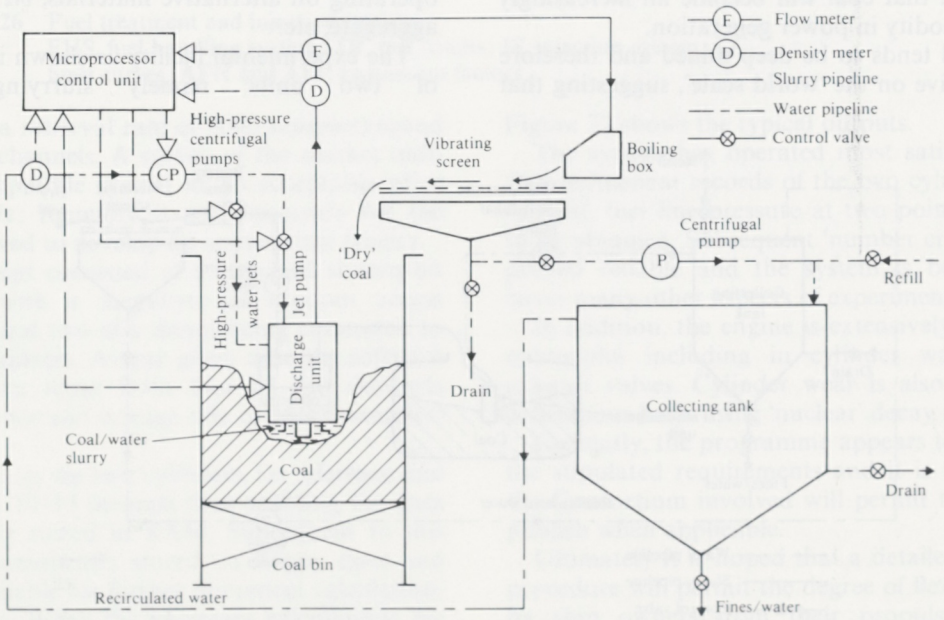


Fig. 30 Schematic sketch of experimental rig for dewatering system

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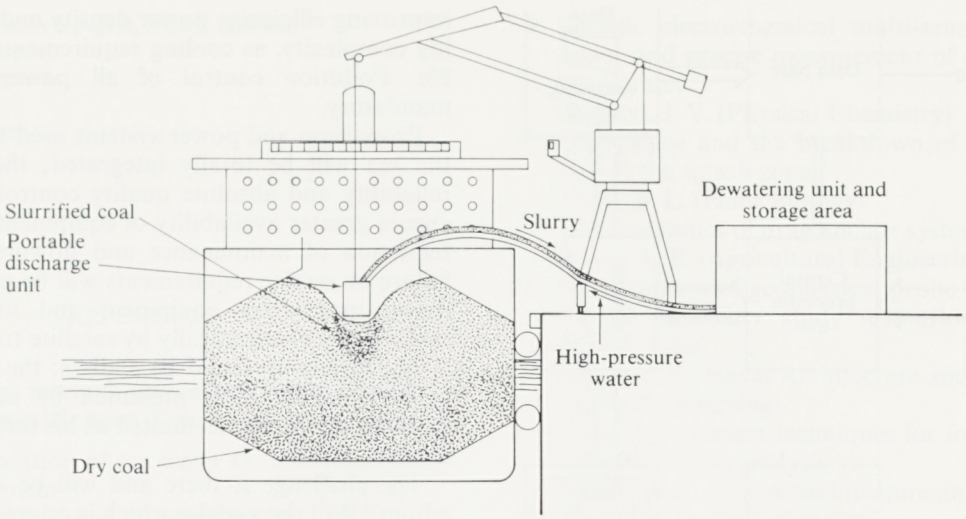


Fig. 31 Alternative mode of operation for coal slurry discharge and dewatering system

developments will lead to a proposal for the consideration of relaxation in the survey regulations, where condition monitoring systems are installed.

The possibility of acceptance of this proposal is dependent on a number of factors which, at a technical level, include:

(a) the level of monitoring;
(b) the reliability of monitoring equipment, i.e. confidence level;
(c) the interpretation of monitoring system output into maintenance requirements;
(d) crew familiarity and training.

The Classification Societies are sensibly preparing to take the lead in this area by directing their attentions to a consideration of these factors. The prime objective of this effort is to compile specifications for acceptable applications for condition monitoring and the equipment used, together with the effects on inspection and survey techniques.

Reference to Fig. 32 (see Ruxton, Appendix No. 4) shows in diagrammatic form the relative complexity of a fully integrated approach to the development, installation and use of a viable condition monitoring system. Failure to achieve a satisfactory level of 'expertise' in any one of the areas shown could negate the value of the whole concept and with it raise the spectre of safety and reliability at sea.

In a 'nutshell' is a Class A1 vessel still a classified vessel when reliance is placed upon condition monitoring equipment for the overall well-being of machinery, ship and passengers? How can the monitoring equipment be classified? What degree of redundancy should be incorporated and how can this be classified for reliability?

The answers to the above questions essentially form the basis of Phase I of this programme. Phase II will optimize on the analysis and hopefully provide the 'best approach' state-of-the-art design concept applicable to marine power plant. Of particular interest will be the substantial definition of prime components to be monitored and the supporting software algorithm associated with the concept.

Phase III will include predictive analysis and performance optimization–control capability with an extension to fuel characterization and system implementation procedures.

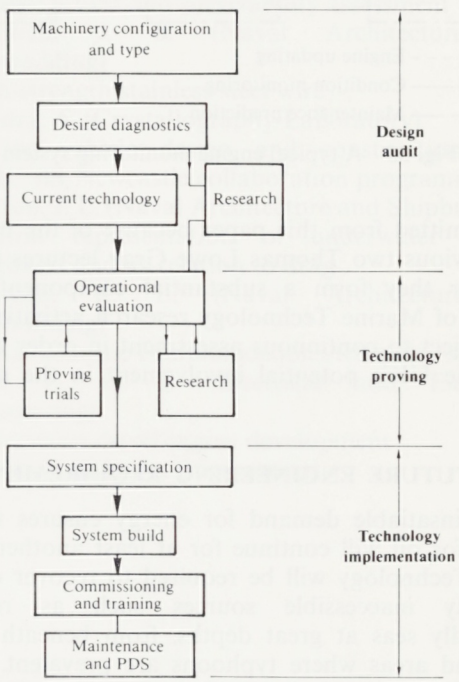


Fig. 32 Flow chart for development of a viable condition monitoring system

Figure 33 shows a typical approach to on-going monitoring which includes the additional option of adaptive control capacity.

4.5 Comments

The research programme alluded to above provides some indication of the approach being undertaken to solve some of the problems associated with conventional operation at sea and the Appendix lists broader aspects of research in marine technology.

Naturally, the achievement of success in the areas indicated requires substantial back-up resource in the form of expertise and experimental facilities, computing, etc.; unfortunately space precludes their inclusion. Furthermore, developments associated with simulation procedures of naval systems and offshore structures have

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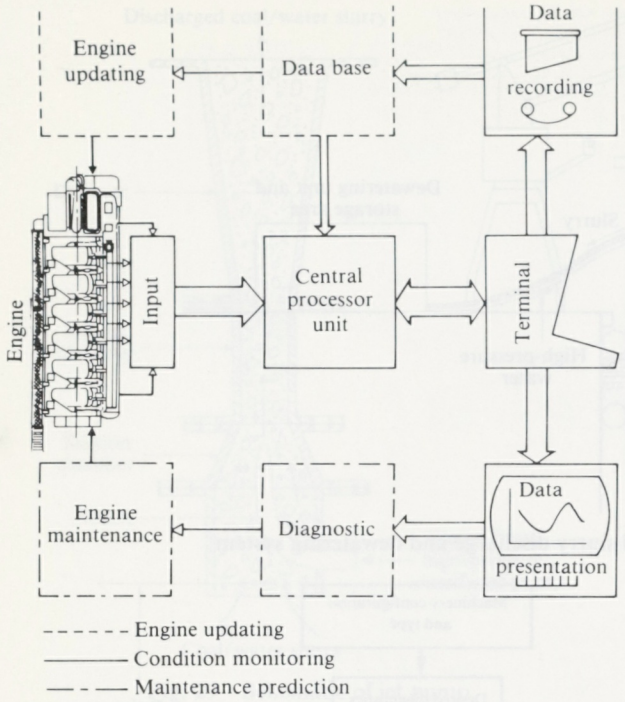


Fig. 33 A typical engine monitoring system

been omitted from this paper because of the nature of the previous two Thomas Lowe Gray lectures (**11**, **12**); however they form a substantial component in the School of Marine Technology research activities which are subject to continuous assessment in order to maximize the UK's potential involvement in the maritime future.

5 FUTURE ENGINEERING REQUIREMENTS

Man's insatiable demand for energy ensures that the search for oil will continue for at least another twenty years. Technology will be required to recover oil from currently inaccessible sources such as relatively unfriendly seas at great depths, from beneath the ice caps and areas where typhoons are prevalent. Subsea power systems and distribution networks will also be the norm.

The manganese nodules which appear at the bottom of the Pacific Ocean as if driven by perpetual motion will require substantial engineering resourcefulness, innovation and investment. To operate equipment and retrieve material economically at depths in excess of 20 000 ft will provide a scale of problem in excess of those currently being overcome in outer space.

Sub-surface farming techniques will probably be in demand in the next century demanding in turn a level of flexibility and reliability in diving and tractive manoeuvrability at least an order of magnitude greater than that currently available. Progress has already been made to allow man to breathe freely below the surface by the use of an artificial membrane which retrieves oxygen from sea water and such activities will continue.

The quest for a further improvement in power generation will continue. The development of new materials based on ceramics and carbon fibre will ensure that the adiabatic engine becomes a reality. No heat will be rejected to the walls of the combustion space, thereby improving efficiency, power density and greatly decreasing complexity, as cooling requirements will be negligible. Pollution control of all power plant will be mandatory.

Propulsion and power systems used above and below the sea will be totally integrated; the application of reliability and absolute quality control techniques will ensure greater availability of equipment together with a reduction of maintenance and down-time. Impending failure or service requirements will be predicted by condition monitoring equipment and urgent difficulties transmitted automatically by satellite tracking systems.

The above list could be endless: the challenge to the professional engineer presented by man's association with the sea is only as limited as his own innovative and creative skills.

The challenge is there and will be accepted, but by whom? Will the malaise which is crippling the UK shipbuilding industry be allowed to continue or will imaginative innovative direction be provided so that the UK and its people capitalize on centuries of indigenous creative skills and acquired technological resource?

Only time will tell.

REFERENCES

1 **Thompson, R. V.** Development of an underwater power generation system. Report to SERC, 1977.
2 **Thompson, R. V.** Subsea power generation, a feasibility analysis. Report to SERC, 1978.
3 **Thompson, R. V.** and **Fowler, A.** Development of a depth independent closed cycle diesel engine. *Proceedings, Offshore Technology Conference*, pp 211–222, Houston, Texas, May 1981.
4 **Thompson, R. V., Hargreaves, M. R. O.** and **Fowler, A.** The development of a microprocessor-based controlled depth independent power generation system. *Proceedings of the Underwater Technology Offshore Petroleum Conference*, pp 159–183, Bergen, Norway, April 1980.
5 **Fowler, A.** Closed-cycle diesel engine for underwater power. *Trans. Inst. Mar. Engrs*, (TM), 1984, **96**, paper 47.
6 **Thompson, R. V.** Application of emulsified fuels to diesel and boiler plant. *Trans. Inst. Mar. Engrs*, (TM), 1978, **91**, part 4, paper 5.
7 **Thorp, I., Armstrong, G.** and **Katsoulakos, P.** The application of oil/water emulsions as a diesel engine fuel. *Trans. NE Cst Instn Engrs Shipbldrs*, **96**, 1980.
8 **Department of Marine Engineering, University of Newcastle upon Tyne.** The evaluation of emulsified fuels in marine diesel engines. Report to Department of Industry, 1980.
9 **Thompson, R. V.** and **Katsoulakos, P. S.** The application of emulsified fuels in diesel engine designs: experimental results and theoretical predictions. *Trans. Inst. Mar. Engrs*, (TM), 1985, **97**, paper 10.
10 **Ng, K. L.** Slurry pumping and dewatering of coal. PhD thesis, 1984.
11 **Adye, A. M.** The role of research in man's use of the oceans. *Proc. Instn Mech. Engrs*, Part A, April 1983, **197**, 79–90.
12 **Neumann, J.** Control of warship machinery. *Proc. Instn Mech. Engrs*, Part D, 1984, **198**(7), 137–151.

Apart from the above references the author wishes to acknowledge copious data retrieval from the following journals and publications:

1 *Marine Engineering/Log International*
2 *The Petroleum Handbook*, Shell International Petroleum Company
3 *World Oil*
4 *Bulletin of Marine Engineering*, Japan
5 *Oil Economists' Handbook*, 1984, ASP
6 *Marine Propulsion International*
7 *The Motor Ship*

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8 *Combustion Research Digest*, AERE Harwell
9 ABS Annual Report
10 Lloyd's List Reports
11 *Offshore*
12 *Offshore Engineer*
13 *Noroil*
14 *Ocean Industry*

APPENDIX

Marine technology research programme, 1983–85 at the University of Newcastle upon Tyne

1. The deoxygenation of sea water for use in marginal field development
   Porter, J. E. (Chemical Engineering)
2. OTEC support research group
   Caldwell, J. B. (Naval Architecture and Shipbuilding)
3. Emulsified fuels in diesel engines
   Thorp, I. (Marine Engineering)
4. Instrumentation—condition monitoring
   Ruxton, T. (Marine Engineering)
5. Characterization of marine residual fuels
   Armstrong, G. (Marine Engineering)
6. Offshore activities in ice-infested waters
   Penney, P. W. (Naval Architecture and Shipbuilding)
7. Short-crested breaking waves (finite depth)
   Denness, B. (Naval Architecture and Shipbuilding—Ocean Engineering)
8. Evaluation of defects in members of structural frameworks using resonance vibration of techniques
   Lilley, D. M. (Civil Engineering)
9. Specific electrochemical multi-sensor for simultaneous and precise measurement of chemical species in seawater
   Dobson, J. V. (Physical Chemistry)
10. Microalgae and the breakdown of protective coatings in the splash zone
    Moss, B. L. (Plant Biology)
11. The mechanics of drag anchor system
    Reece, A. R. (Agricultural Engineering)
12. Development of geophysical probe from laboratory triaxial feasibility study (extension of Newcastle project 1.2b)
    Denness, B. (Naval Architecture and Shipbuilding—Ocean Engineering)
13. Boundary element techniques for free surface structure interaction analysis
    Hearn, G. E. (Naval Architecture and Shipbuilding)
14. Second order fluid damping
    Hearn, G. E. (Naval Architecture and Shipbuilding)
15. Marine hazard and survivability assessment
    Caldwell, J. B. (Naval Architecture and Shipbuilding)
16. High-strength stainless steel wire
    Hendry, A. (Crystallography Laboratory)
17. Marine vehicle design and construction (joint SERC/BS/Newcastle collaboration programme)
    Buxton, I. L. (Naval Architecture and Shipbuilding)
18. Spectral representation of underwater surface roughness and its relation to drag
    Townsin, R. L. (Naval Architecture and Shipbuilding)
19. Digital acoustic communications/telemetry system
    Holt, A. G. J. (Electrical and Electronic Engineering)
20. Underwater diesel engine development
    Fowler, A. (Marine Engineering)

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A. Bell (1)

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LLOYD'S REGISTER TECHNICAL ASSOCIATION 1920—1985

Born 1920 and Still Going Strong

SIXTY-FIVE YEARS IN RETROSPECT AND PROSPECT

This index records 330 papers presented to the Association over a period of sixty-five years and it is hoped it will be found to provide a useful and convenient source of reference.

As with the previous issues, this presentation gives the opportunity to offer some information about the Association to those who may find it of interest and who perhaps have joined the Society since the last issue of the index in 1980.

The Association was founded on the 6th October 1920 at the London Headquarters.

The first President was Mr W. Watt, who at the inaugural meeting said:

> "The formation of the Association commences another chapter in the long and honourable history of Lloyd's Register and I venture to think that in it we will write a chapter which will hold its own with any that have gone before."

Mr Watt's prophetic words are seen to be well realised by examination of the papers listed in this index. Mr Watt went on to comment about specialisation in the Society and again the accuracy of his observations have been borne out and are seen to be increasingly true, having regard to the technical change which the papers reflect in their diverse and distinctive ways. Over the period of 65 years the Society's activities have widened considerably and extend into fields of technology undreamed of in 1920. The Association's transactions not only reflect such development but also as the years pass acquire historical value in recording the technology of their day. In this way the transactions are unique in the Society's affairs and records for nowhere else within the Society are such records to be found. The papers are distributed world wide and this adds in no small measure to their value for it greatly facilitates access by those who seek the information which the papers offer. So it can be said that the transactions are not only a means of storing and retaining past experience but also a means of disseminating knowledge of present practice which is the aim of the Association.

The object of the Association, as stated in its present constitution is:

> "The advancement and dissemination of knowledge among its membership in respect of Shipbuilding, Marine Engineering and other subjects of technical interest by the preparation, discussion and circulation of technical papers".

This object is achieved by the presentation and discussion of papers written by members and invited authors. From 1920 to 1970 it was known as Lloyd's Register Staff Association but received its present title in 1970.

Many of the papers have proved to be of direct practical help to surveyors in the course of their duties world-wide, again demonstrating not only their value but also the achievement of the object of the Association. Having regard to the scope of the Society's activities it is self evident that there is as much and probably greater need now for papers on a variety of subjects, both general and specialist, as there has ever been during the past sixty-five years, having regard to the diversity of work upon which surveyors are called to engage.

That the present era is one of increasing intensity of technological advance is self evident, especially in the Society's activities, and is reflected in the transactions. Such developments provide opportunity and challenge to all members of the Association to add to the pages of the transactions by the presentation of papers thus maintaining the purpose for which it was founded in 1920.

Although the Technical Association plays no part in any official capacity in the business of Lloyd's Register of Shipping and its operation and direction from Head Office are only matters of administrative convenience, its value to the Society requires no justification. The service it performs is very largely due to the many honorary committee members and outport representatives who have served over the past sixty-five years and who continue to do so today.

In addition to what is hoped will be a useful reference, the index also provides a means of bringing the names of some of our respected predecessors to present members of the Association. Generations come and go on the tides of time and it is hoped some worthwhile continuity will be found in scanning through the index, valued, and handed on in the Association's affairs.

It is also hoped that the index will offer some guide and perhaps stimulation to subjects which may be usefully dealt with in the future, bearing in mind how the papers have served in the past. Many papers found helpful in the past could be brought up to date with much advantage to present technical staff. Mr Watt said in 1920 that the field was large and the subjects numberless. In 1985 his comments must be even more applicable.

These notes provide the opportunity of drawing members attention to the generosity and support of the General Committee of Lloyd's Register of Shipping, without which the Association could not have functioned for the past sixty-five years and accordingly it is felt that all members would wish to express their appreciation of the General Committee's interest and assistance in this connection. Appreciation must also be expressed to the Printing House Staff who over the years have played their particular part in the Association's affairs. Without their help there would be no papers.

Finally, it is desired to express very grateful thanks to Mrs R. J. Hook for without her help there would be no index. Her professional help as a librarian experienced in cataloguing and indexing has made this index and its four predecessors possible.

The index has been compiled at five yearly intervals for nearly twenty-five years by the present compiler and has been considered hopefully to have been a worthwhile task. However the tides of time wash ever closer and the time has come for the task to be passed on. It is hoped someone will be found to continue it.

At sixty-five years the Association is happily, far from pensionable age. It would seem true to say "Born 1920 and still going strong" long may it continue.

> "Astern our annals proudly stand,
> Ahead brightly shines the foremast light."

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